Design of Strom water Management system: Using GVF Rational Method

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Abstract – Storm water management refers to the practices, policies, and techniques used to manage the flow, quality, and quantity of rainwater runoff. This is essential in urban areas or areas with large amounts of impervious surfaces (e.g., roads, parking lots, buildings) that prevent water from naturally soaking into the ground. Effective storm water management helps prevent flooding, reduces erosion, and protects water quality by controlling the runoff and ensuring that it does not carry pollutants into rivers, lakes, or oceans.

The GVF Rational Method is used to design storm water systems, particularly in urban areas. It's a method that focuses on determining peak flow rates for the design of storm water systems, like culverts, gutters, or pipes. The GVF in the name stands for Generalized Variable Flow which refers to the approach for modelling the flow of storm water through the drainage system, considering varying flow conditions.

The Key Objective of Storm water management is Flood Control, Water Quality Protection, Groundwater Recharge, Erosion Control and Sustainability

In the context of modern urban development, storm water management aims to replicate the natural hydrologic conditions as much as possible. This can be achieved through a variety of techniques designed to capture, store, treat, and safely convey storm water runoff.

Effective storm water management is essential for minimizing the environmental impact of urbanization and preventing flooding, water quality degradation, and erosion. By using a mix of structural solutions, green infrastructure, and best management practices (BMPs), communities can manage storm water in a way that is both sustainable and environmentally responsible. The key is to design systems that mimic natural hydrological processes, improve water quality, and ensure the long-term resilience of both the built environment and the surrounding ecosystem.

Key words - GVF Rational Method, Flow, Culverts, Flood Control, Water Quality Protection, Erosion Control and Sustainability, Structural solutions.

1.INTRODUCTION

Pune is the second largest city in Maharashtra with an area of about 324.00 sq.km (243.00 sq.km. of Pune city area + 81.00 sq.km. of 11 newly added villages) and with about population of city census (2017) 48.52 Lakh people residing.

On 30th June 2021, 23 additional villages (Mhalunge, Sus, Bavdhan, Pisoli, Kondhwe-Dhawade, Kopre, Nanded, Khadakwasla, Mundhwa, Manjari, Narhe, Mantarwadi, Holkarwadi, Handewadi, Wadachiwadi, Shewalewadi, Mangdewadi, Vadgaonsheri, Nandoshi, Bhilarewadi, Jambhulwadi, Gujar-Nimbalkarwadi, Kolewadi) were added to Pune Municipal Corporation. The adjoining villages which are now merged in Pune are already urbanizing rapidly and are expected to grow more now that they are part of the urban conglomerate.

Pune Municipal Corporation prepared Storm water master plan in Year 2007. Then after merged 12 Village (Yewalewadi + 11 Village) departments also prepared storm water master plan in year 2018. This includes study of existing Storm network and proposing revamping of inadequate network as well as new network and construction of Culverts facilities in phased manner.

Considering the expected rapid growth in the newly merged 23 villages having area approx.181 sqkm, Pune Municipal Corporation aims to prepare a comprehensive Storm master plan for the newly added area. This master plan is proposed to be developed such that it can dovetail into the existing master plan so that a seamless development of Storm water collection and as to provide a system wherein no water logging occurs in the newly merged 23 Village and Bavdhan villages is one of the village from 23 newly Merge village in PMC and we are going to look for Bavdhan storm water management.

Recently 23 fringe villages included in the Pune Municipal Corporation city limit. At present total area of Pune city increased from 333.69 Sq.km to 581.30 Sq. km., highlighted marked area in yellow color shown in above figure is the villages added in Pune Municipal Corporation city limit and we are going to look for Bavdhan Strom Water Management.

2. OBJECTIVES AND SCOPE

2.1 Objectives:

The **objective of a Stormwater Master Plan (SWMP)** is to provide a comprehensive, long-term framework for managing stormwater runoff in urban and rural areas to reduce flooding, protect water quality, and promote environmental sustainability. Specific objectives include

1) Flood Risk Management
2) Water Quality Protection
3) Regulatory Compliance
4) . Sustainable Urban Planning
5) Environmental Conservation

2.2 Scope:

1. Collecting Village maps, DP or Regional Planning map from with Pune Municipal Corporation and toposheets from respective government department.
2. Preparation of base map of newly merged 23 villages by using available satellite image of with Pune Municipal Corporation. This will include existing roads, natural streams, village maps and important landmarks etc.
3. Topographical survey by using total station/DGPS of all existing roads & existing natural streams (nalla).
4. Creating sub-watersheds (Basins) based on topography of the project area and outfalls of natural streams (nalla).
5. Marking proposed storm water drainage network and nodes within the sub-watersheds (basins) by identifying the existing roads and natural streams (nalla), which will carry the storm water to the outfall of natural stream.
6. Historical Rainfall data collection of the nearest rain-gauge station form Indian Meteorological department, rainfall analysis and generating Intensity-Duration-Frequency (IDF) curve as per CPHEEO manual for storm water drainage system.
7. For the roads and streams (nalla) identified, design storm water drains with carrying capacity for intensity of return period as suggested in CPHEEO manual. Hydraulic design shall be as per CPHEEO manual.
8. Evaluate current carrying capacity of natural streams (nalla) in the project area and provide recommendations on possibilities of increasing the capacity.
9. Identifying frequently flooding spots and encroachment of natural streams and recommend appropriate measures to solve the problem of water stagnation at these spots.
10. Showing storm water network in GIS map with attributes like estimated runoff, proposed sizes of drains etc.

3. Limitation and Research Gap

3.1 Inadequate Flood Mitigation in Urban Areas

- **Limitation**: Many traditional storm water management systems, such as **pipe-based drainage** and **storm sewers**, are often inadequate in managing large volumes of water during extreme rainfall events. These systems tend to focus on **flood prevention** through rapid conveyance but are not optimized for **storm water storage** or for dealing with the increasing frequency and intensity of heavy storms due to climate change.

- **Research Gap**: There is a need for **advanced modelling** to improve flood prediction under changing climate conditions. More research is required to integrate climate change projections into urban drainage system design, particularly to enhance **resilience** and manage **flash floods**.

3.2 Insufficient Treatment of Storm water Pollutants

- **Limitation**: Traditional systems often fail to adequately treat storm water runoff, especially in urban areas with high levels of **impervious surfaces** (e.g., roads, buildings), leading to the **transport of pollutants** such as **nutrients**, **heavy metals**, and **oils** into water bodies. While systems like **detention ponds** and **swales** help reduce runoff, they may not always meet stringent **water quality standards**.

- **Research Gap**: More research is needed into innovative filtration technologies, including the use of bioretention systems, constructed wetlands, and advanced stormwater treatment methods. Additionally, developing systems that can remove emerging contaminants (e.g., pharmaceuticals, microplastics) is an urgent area of study.

3.3 Lack of Integration of Green Infrastructure

- **Limitation**: Despite the increasing recognition of green infrastructure (GI) techniques, such as rain gardens, permeable pavements, and green roofs, these solutions are still underutilized in many cities. Traditional infrastructure often prioritizes short-term flood control over long-term water management and environmental benefits.

LID Control Type	Description
Bio-Retention Cell (BIO)	Shallow depression with soil media, underdrain, and vegetation
Infiltration Trench (ITR)	Gravel-filled trench allowing stormwater to infiltrate into the ground
Permeable Pavement (PP)	Pervious surface with structural support allowing infiltration
Rain Garden (RG)	A variation of BIO without underdrain
Rain Barrel (RB)	Above-ground cistern storing roof runoff
Rooftop Disconnection (RD)	Directing rooftop runoff to pervious areas
Vegetative Swale (VS)	Shallow, vegetated channels slowing and infiltrating flow
Green Roof (GR)	Vegetated rooftop system for stormwater retention

- **Research Gap:** Research is needed to evaluate the performance and cost-effectiveness of various green infrastructure solutions, particularly in terms of storm water infiltration and pollutant removal under different climatic conditions. There is also a need for studies on the integration of GI with existing grey infrastructure, such as when combining permeable pavements with conventional storm water systems.

3.4 High Costs and Maintenance of Storm Water Infrastructure

- **Limitation**: The initial capital investment for advanced stormwater management technologies, such as rainwater harvesting systems, green infrastructure, or large-scale treatment facilities, can be prohibitively high. Additionally, maintenance of stormwater systems, especially GI systems, requires ongoing monitoring and maintenance to ensure their effectiveness over time.

- **Research Gap**: Further investigation into the life cycle costs of stormwater management infrastructure, including both initial construction and long-term maintenance, is needed. Research should also explore financial models and policies that encourage the adoption of cost-effective storm water management techniques, particularly for low-income or developing urban areas.

4. Methodology and Design

A) Methodology

4.1 Base Map

The base map prepared for all villages by using geo referenced satellite image of year 2014 provided by IT department, Pune Municipal Corporation (PMC) Village maps of 23 villages and DP map of Yewalewadi provided by DP cell of PMC. These village maps were scanned and geo-referenced as per satellite image of year 2014 and digitized. The village wise base map prepared by digitization of satellite image, village maps, OP. map & toposheets. All the existing river, nallas, streams, roads, revenue survey numbers and its boundaries are digitized and shown in base map.

4.2 Reconnaissance Survey

Each and every nalla/stream in base map visited on ground to as certain existing condition of nalla / stream, open nalla, partially encroached nalla, fully encroached nalla, undeveloped nalla, underground nalla etc.

- **Streams:** From site visits it is observed that in case of primary drains i.e. starting stage of nalla/stream, water course does not develop on ground but there is a natural low-lying area which carries the storm water during rains. These primary drains which do not have regular water course (unseen nalla width and depth) considered as streams (undeveloped nalla) in master plan.

- **Nalla:** Natural Nalla exists with water course seen width and depth from which storm water flows.

- **Fully encroached nalla and streams:** Existing nalla/stream course obstructed due to construction activity and by earth filling etc. These spots were probable flooding location and marked in yellow colour in drawings.

- **Partially encroached nalla and streams:** Existing nalla course partly obstructed due to development activity along the nalla course such as construction, earth filling etc causing resulting smaller/inadequate section for draining storm water. These spots were probable flooding location and marked in yellow color in drawings.

- **Underground nalla and streams**: Existing natural nalla constructed in concrete box drain or by using RCC pipes.

4.3 Topographic Survey

The topographic survey carried for all all-existing roads and nallas where nalla course exists i.e. nalla has width and depth and network in project area by using electronic total stations. For undeveloped nalla/streams, satellite image is used for alignments, levels and designs. The land marks, c.d. works and water bodies like captured and marked on the map. The contour map of surveyed area is prepared by using this total station survey data. Contours are trimmed in unsurvey area. The survey data & contour data of all nallas and road network superimposed over base maps. All nallas and streams shown on Development Plan/village maps are considered for design even some nalla are fully/partially encroached.

4.4 Catchment Area

Catchment area of main nalla and its tributaries is marked by using toposheet. The catchment area outside the project area is also considered for design Coefficient of runoff in project area is considered as proposed land of residential area high density, as work DP map preparation of these villages are in progress. Catchment area outside the project area, coefficient runoff is considered by predicting the future growth and there by change in land use from agriculture to residential/commercial use.

4.5 Basin

As all the villages are scattered along the old PMC boundary, Basin boundaries (23 basins) of old PMC limits are not revised as it has basin code based noding system. Under storm water master plan for newly merged 23 villages, village boundary is considered as a project area.

4.6 Noding

As per old master plan of Pune city 23 basins has given the basin name from A to W. These initial is connected as a suffix with the numerical value for Node and nalla number of the basin to know the basin by reading node numbers. This method is not adopted for these 23 villages because it may be possibility of duplicate node numbers in old 23 basins and these 23 villages. Hence separate system for nodding is defined for nalla.

4.7 Proposed Nalla Section

Under Storm Water Master Plan, nalla section with natural bed and RCC retaining/protection wall on both banks is proposed. Natural bed allows precipitating the storm water into ground and will help to recharge the surrounding area

B) Network Design

4.8 Software Used

The hydraulic analysis of collection network of proposed network is carried out using "Storm CAD"

Purpose	Description
Stormwater Drainage Design	Design and analysis of stormwater drainage systems, including open and closed conduits.
Hydraulic Modeling	Performs steady-state hydraulic analysis using rational method calculations.
Inlet Capacity Analysis	Evaluates capacity of inlets (grates, curb openings, combination inlets, etc.).
Gutter Flow Calculations	Simulates gutter flow and spread width for surface drainage analysis.
Design of Storm Sewers	Sizes storm sewer pipes based on peak flows, slope, and cover requirements.
Inlet Spacing and Placement Optimization	Helps optimize locations and spacing of inlets for efficient drainage.
Catchment Area Management	Assigns catchment areas to inlets and calculates runoff using rational method.
Pipe Sizing and Slope Optimization	Automatically resizes pipes and adjusts slopes to meet design constraints.
Manhole and Junction Analysis	Analyzes hydraulic performance of manholes and junctions in the network.
Scenario Management	Allows comparison of multiple design and analysis scenarios.
Design Reports and Profiles	Generates design spreadsheets, longitudinal sections, and detailed reports.
GIS and CAD Integration	Integrates with GIS and CAD platforms for seamless data exchange and mapping.

4.9 Data Integration on Base Map

Base Map: Layer The new survey of nalla and road network is imported in the software in the format of CAD file or Esri. Shape file. GL at various nodes is obtained through the Trex-tool in Bentley.

All related parameters (pipe diameter or box span and rise, material, c value, status, Tc, runoff coefficient) are assigned to node, pipe network & catchments.

Similarly, length is obtained automatically from scaled Survey base map.

Activity No. 1: INPUT DATA

The Rainfall data is collected from the authority and IDF curve is prepared for a particular return period and it is used to forecast the maximum rainfall in the future.

time in min	Intensity in mm/hr
5	378
10	224
15	165
20	133
30	98
40	79
50	66
60	58
70	52
90	43
100	39
120	34
150	29
180	25
210	22
240	20
300	17

Activity No. 2: FORMATION OF SERVICE POLYGON LAYER

Catchment Area's are created through Arc GIS tool or manually from Google Earth Pro Software's and further it is assigned to network catch basins using Thissen Polygon and model builder tools. The service area polygon is prepared using the Thiessen Polygon tool in Bentley.

For each catch basin (Point) Thiessen polygon defines a region around each point. A Thiessen polygon divides a plane such that each point is enclosed within a polygon and assigns the area (service area) to a point in the point set (the point set being the nodes). A Shape file of the command area is import for the formation of these service areas; Further the entire command area gets divided into number of service polygons, served by each respective node. After assigning a check is done for ensuring the rain fallen in the polygon area is collected in the respective catch basin and changing the area of polygon according to it.

The service polygons represent serving area for each node (The catch basin carries the runoff of the rainfall from the respective service area).

REFERENCES

1. **Ministry of Housing and Urban Affairs (MoHUA) –**

   MoHUA has issued guidelines on urban drainage and storm water management that focus on improving infrastructure for handling runoff in cities.

2. **Central Pollution Control Board (CPCB)**

   The CPCB is responsible for monitoring and controlling pollution in India, including storm water runoff that carries pollutants like sewage, heavy metals, and chemicals. They offer guidelines for stormwater management in urban areas.

3. **Central Public Health and Environmental Engineering Organisation (CPHEEO). (2019).**

   Manual on Strom water drainage system. Ministry of Housing and Urban Affairs, Government of India.

4. **Manual on Stormwater Drainage Systems" by M. S. Ramaswamy**

   This book provides detailed technical guidelines and case studies on stormwater drainage systems and is widely used by civil engineers working in India.

5. **A World Bank Reports on Urban Flooding and Storm water Management**

   The World Bank, in collaboration with the Indian government, has published reports on storm water management in Indian cities, focusing on flood mitigation and climate resilience.