iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** VI **Month of publication:** June 2020

DOI: http://doi.org/10.22214/ijraset.2020.6216

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue VI June 2020- Available at www.ijraset.com

Stormwater Analysis and Solution of Waterlogging in Kothrud Region, Pune

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Abstract: Stormwater is the water flow generated from rainfall. Rainfall that flows over the ground surface is created when rain falls on paved surfaces like road, parking lot, rooftop and other concrete surface that do not allow water to soak into the ground. This research focuses on high intensity storm rainfall and runoff in the Kothrud region of Pune city and the problems due to lack of proper drainage system and insufficient management. It also includes water logging problem, its cause and its effect and living style of the city. The major issue because of this problem is traffic and loss of income potential for road dwellers. The storm water becomes polluted as it is mixes with various solid waste, domestic waste and other human wastes. Such lack of cleanliness can result in epidemic and health disorders.
Keywords: Runoff, water logging, paved surfaces, land use, urban flooding.

I. INTRODUCTION

Stormwater runoff is a rainfall that flows over the ground surface. In the recent years due to development and urbanisation, there is an increase of impervious surfaces which has increased the risk of flooding. The actual physical processes that convert rainfall to runoff are highly variable. Therefore by the use of simplifying assumption and empirical data, there are several mathematical models and equations that stimulate these processes and predict resultant runoff volume. The selection of appropriate model or equation depends upon a number of factors viz; method of calculation of runoff, drainage area size, data availability, etc.

In general, all computation methods are the mathematical expressions of the hydrologic cycle to some degree. As shown in Fig 1 below hydrological cycle depicts both primary forms that water can take and the cyclical processes that produce them. These processes include precipitation, evaporation from surfaces or the atmosphere, evapotranspiration by plants and infiltration into the soil or groundwater.

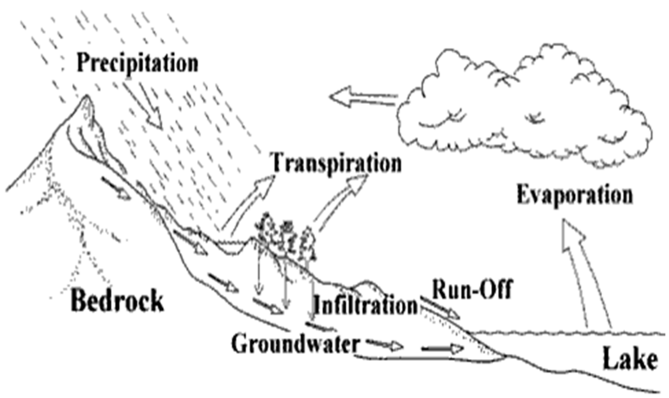

Fig 1 : Hydrological Cycle

In short, rainfall is generally characterized by its size, intensity and the frequency of occurrence. The size of a rain storm is the total precipitation that occurs over a particular duration. Since storms have mathematically random events, their recurrence can also be specified as an annual probability.

$$\text{Annual probability (\%)} = \frac{100}{\text{Recurrence interval (years)}}$$

For reducing runoff flood damages, there are two common approaches are as follows:

1) Structural measures (e.g. reservoir)
2) Non Structural measures (e.g. watershed approach)

Structural measures can reduce the floodplains in several ways, like

a) Reservoir reduces downstream peak flow rates.
b) Flood walls continue the flow of the rivers.
c) Flood ways help to divert excess flow.

Structural measures can be effective in reducing floods but are used for small parts of watershed (river) for flood management. There is a new emphasis on evaluating non-structural and watershed management approaches to determination and mitigation. Within a watershed, ponds and wetlands are able to absorb and hold greater amounts of floodwater. A report of the United Nations (UNISDR 2006) concluded that wetlands could be effective for small floods. But for larger floods produced from rainfall over a continuous period results that ponds are insufficient to use so the excess water must be stored in storage structures such as reservoirs or artificial storage concrete tanks.

II. METHODOLOGY

A. Computation of Stormwater Runoff

Studies of rainfall records show that actual storm distribution and durations can vary considerably from event to event. It may be evenly distributed or can vary widely within the same period. Many methods, including rational and NRCS methods, rely on a hypothetical event known as design storm for their rainfall input. To use a design storm, we take some assumptions about the antecedent ground and waterway conditions to exist at its start.

In addition to rainfall and antecedent conditions, other factors that significantly affect both runoff volume and peak discharge are the hydrologic characteristics of the soils in the watersheds. Those covers may vary from pervious surfaces like grass to impervious surfaces like roads.

Runoff Computation Methods

1) Rational Method
2) Modified Rational Method
3) NRCS Methodology

The primary method used to determine peak runoff is the rational method. The Rational equation is given as:-

$$Q = C.I.A \qquad \text{-----(1)}$$

Where, Q = Estimated design discharge (ft^3/sec)
C = Runoff coefficient for watershed (composite)
I = Rainfall intensity (inch/hour) for design storm
A = Watershed area (acres)

The runoff coefficient is determined by estimating the area of different land uses within drainage areas. The range of runoff coefficient values varies from 0-1. Higher values correspond to greater runoff potential.

Table 1 (Runoff Coefficient)

Description	Runoff Coefficient C
Roads & Pathways	1.0
Residential / Industrial / Commercial, fully paved, high density	0.95
Residential / Industrial / Commercial, largely paved, medium density	0.85
Residential / Industrial / Commercial, moderately paved, low density	0.75
Open ground with bushes, steep slopes	0.5
Open ground / gardens / lawns, low to moderate slopes	0.3

The intensity of rainfall is calculated by formula:- $\text{Rainfall Intensity (in/hr)} = \frac{\text{Total amount of rainwater (in)}}{\text{Duration of rainfall (hr)}}$

B. Runoff Volume

There are two primary methods that can be used to determine the volume of runoff from a given design storm:

1) The Simple Method.

2) The discrete (SCS Curve Number Method)

a) *Simple Method:* The simple method uses minimum information such as watershed drainage area, impervious area and the design storm depth to estimate the volume of runoff.

The runoff volume is given by the formula

$$V = 3630\ R_d\ R_v\ A \qquad \text{------(2)}$$

Where V = Runoff Volume (ft^3)

R_d = Design Storm rainfall depth (inch) = 1.0 or 1.5

R_v = Runoff Coefficient (unit less)

A = Watershed area (acres)

$R_v = 0.05+0.09\ I_a$

Where

I_a = Impervious fraction = Impervious portion of drainage area / Drainage area (unit less)

III. SOLUTION OF WATER LOGGING

As we discussed earlier, provision of structural and non-structural measures reduces or prevents water logging problems. As going further, the development or redesign of drainage networks reduces stormwater runoff problems and thereby water logging conditions which causes various problems.

The actual solution of prevention of water logging is divided in some steps:-

1) Selection of catchment area in engineering approach.

2) Provision of structural or non-structural measures.

3) Introduction of stepped ponds above the reservoirs and Geosynthetic fibres.

4) Introduction of siphon technique for discharge of water.

5) Modification (or) redesign of drainage line network.

A. Selection of Catchment Area

In this research, we have selected Kothrud, Pune area for the research work due to its topographic features like mean level height and hills.The hills tend to drop there showers received on to the planar region down on the paved and developed areas. This results in increment in flooding and waterlogging in that area and if runoff is more or rainfall continues for a longer duration.

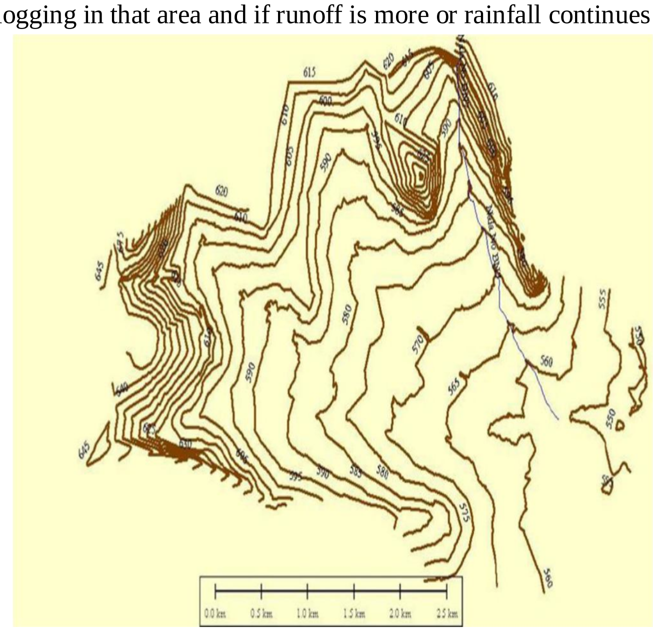

Fig 2 : Kothrud Region with DEM

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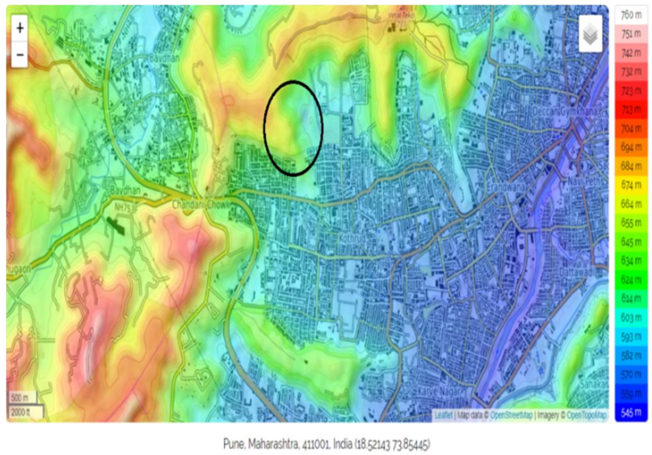

Fig 3 Pune, Maharashtra, 411001, India (18.5214373.85445)

The Kothrud is surrounded by some of the hilly areas such as Chadani Chowk and Vettal Tekdi. We understood from the figure that the height of Kothrud Region from mean sea level is below 600m and the height of Chadani Chowk and Vetal Tekdi is above 684m. When the rainfall occurs, the runoff produced from Vetal Tekdi and Chadani chowk directly comes in the Kothrud area and it creates flooding problems if runoff is more or rainfall continues for a longer duration. Another main factor to select that area is land use pattern in Pune.

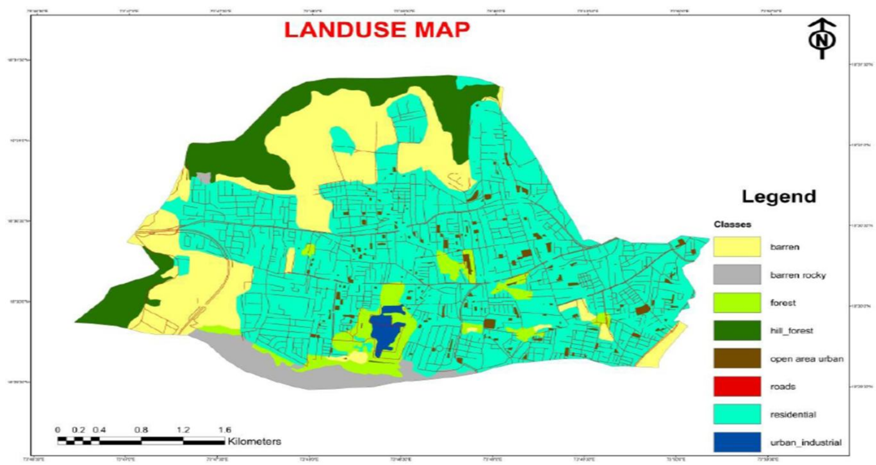

Figure 4 : Land Use Map of Selected Catchment (Source PMC)

Figure 5: City view in 2008 and 2018

From the figures, we saw that there is an increase of areas like residential, industrial due to which the paved area increases which does not help the soil to infiltrate water. This further results in an increase of runoff condition in the Kothrud area.

B. *Provision of Structural and Non Structural Measures*

1) *Structural Measures:* Non-linear reservoir methods for rainfall runoff simulation can also be used to compute runoff quantity for single vent.

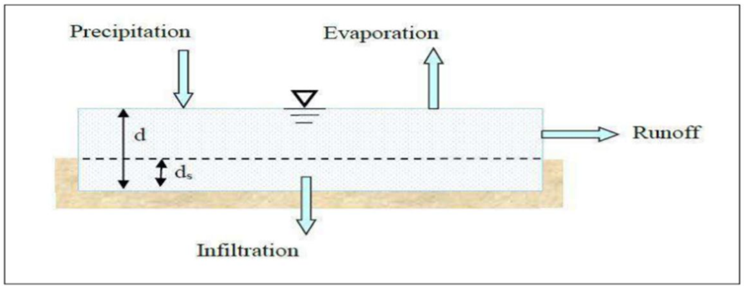

Fig 6 : Nonlinear reservoir model

From the above fig, sub catchment inflow is precipitation and outflow runoff and losses are evaporation and infiltration. The depth of the reservoir is d, and the depression storage depth is ds.

From conservation of mass, net change in depth is given by

$$\frac{Dd}{Dt} = i - e - f - q \qquad \text{------(3)}$$

Where, i = rate of rainfall. f = infiltration rate.
q = runoff rate e = surface evaporation rate.

To find out runoff's volumetric flow, Q ; assuming that sub catchment surface behaves as uniform flow within rectangular channel of width 'w', height 'd-ds' and slopes.

By using Manning's equation

$$Q = \frac{A}{N}\left(R^{2/3} S^{1/2}\right) \qquad \text{------(4)}$$

Where, N = Manning roughness coefficient.
S = Average slope of catchment.
A = Area across catchment for runoff flow.

Water or runoff always flow from upstream to downstream. From hilly or highly elevated areas, after rainfall huge amounts of rainfall runoff starts flowing in downward direction which may create stormwater flood runoff conditions.From the two figures above, the highlighted position shows that the area which is suitable for a small reservoir. We conclude to build a reservoir at an elevation of 670m from MSL, which will store water for future use. We selected the elevated area near Matoba Nagar for construction of the reservoir. When heavy rainfall occurs, the runoff from hilly areas starts flowing towards low elevated areas on the way to Kothrud region and creates storm flood or water logging problems. So a reservoir construction will help to stop this runoff flow into the urbanized area and store water which may be further used for industrial and factories purposes.

Fig 7: Map structure of Reservoirs

2) *Non Structural Measures (Siphon Technique):* For remote and dynamic release of water from reservoirs or ponds, we plan to design a siphon system that can be remotely operated. This system requires a simple anchoring of siphon pipe, SCADA - type control for remotely operation which can be activated through direct Satellite or wireless radio. It doesn't need a significant energy except for keeping the siphon full and for opening and closing of downstream valve for which a small solar panel can be used.

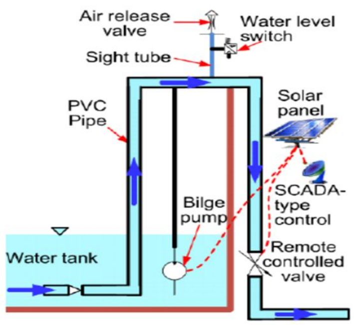

Fig 8: Siphon technology with prototype

Siphon techniques work on the principle of difference in pressure between atmospheric pressure at the upper reservoir and negative gauge pressure at the top of siphon. It is used for effective removal of water from reservoirs. Siphon requires minimal oversight. The main advantage include once the flow is started, a siphon requires no electricity to keep the liquid flowing up and out of the reservoir. Siphon will draw water out of the reservoir until the level falls below the intake, allowing air to break the siphon flow. When the liquid pressure in the siphon drops below vapour pressure, tiny bubbles begin to form at top of siphon, which stop the flow. There is a limit for the height of siphon pipe above the reservoir water elevation. For water at standard atmospheric pressure, maximum siphon height is approximately 10.3m. In practice maximum height should be smaller than 10.3m due to head losses and evaporation.

3) *Analytical Solution:* Siphon flows can be analysed using the energy equation of fluid flow as shown below

$Z_a + P_a + Va^2/2g = Z_b + P_b + V_b^2/2g + h_f + h_m$ -----(5)

Where,

Z_a = Elevation of reservoir water surface.

Z_b = Elevation of pipe centreline outlet.

P_a = Pressure at reservoir water surface.

P_b = Pressure at reservoir outlet surface.

Va = Velocity at pond water surface.

V_b = Velocity at point b.

γ = Specific weight of water.

g = gravitational acceleration.

h_f = Total head loss due to pipe friction.

h_m = Sum of local head losses.

The velocity at point a is relatively small w.r.t velocity at outlet point b, found by

$Vb^2 = 2g(Za-Zb-hf-hm)$ -----(6)

Darcy - Weisbach equation used for calculating frictional losses.

$h_f = F\ L\ V^2/2g$

Where, f = Pipe friction factor.

L = Length of pipe.

V = Cross Section flow velocity.

D = Diameter of Pipe.

The local head loss is given as

$h_m = \sum ki\ V^2/2g$

Where, k = head loss coefficient for particular pipe fitting.

IV. WHY USE SIPHON?

The main aim to construct a reservoir is to store runoff water to avoid entering runoff in city or paved areas. For prevention of waterlogging the reservoir is constructed at elevated surface, when the extreme rainfall condition occurs, the discharge water from the reservoir gets difficult and if this discharge may not be done in some critical case, it may result in failure of the reservoir and the whole water stored in the reservoir comes into the city congested areas. To avoid this condition and for safety of the reservoir from the various forces acting on the reservoir point of view, siphon technique is used.

Siphon automatically discharges water when overflow condition takes place and also helps to discharge water at regular intervals. This is not done by only a drainage network. So we have to add siphon technique for prevention of flooding.

V. USE OF GEOSYNTHETIC MATERIALS, STEPPED PONDS AND CASCADE DRAINS ABOVE THE RESERVOIR.

A. Geosynthetic Materials (Geogrid)

Geosynthetic or geosynthetic materials are nothing but planar synthetic or natural materials used in contact with soil or rock for filtration, drainage, separation, reinforcement, protection, sealing and packing. Geosynthetic materials are eco-friendly and less costly.

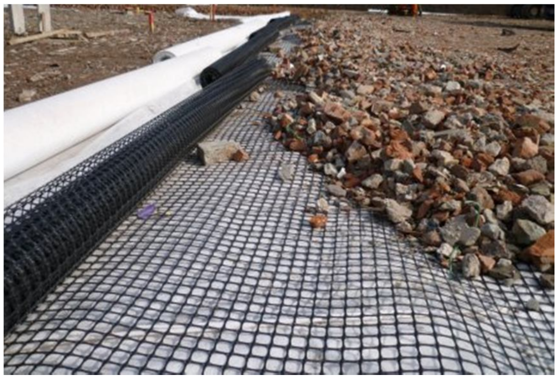

Fig 9: Geogrid or Geocomposite liner

An increase in water level, introduces an increase in pore water pressure. It requires then a surplus amount of reinforcement of about 50% to avoid this geocomposite liner is installed usually at the back of reinforced structure with a perforated pipe at the bottom to collect water. The pipe is then connected to hydraulic structures. Geosynthetic materials absorb or help in balancing load from water and soil above the reinforced structure. It also helps in prevention of landslides due to pore water pressure.

B. Cascade Drains

Cascade drain helps to bring out water at a particular point. This alternative to stepped ponds cascade drain is one of the hydraulic structures that are widely used in slope condition areas. The functions of cascade drain is to control and convey flows from the surface runoff at upstream to downstream. There were different types of cascade drain which are horizontal step, end sills step and inclined step. Mostly used cascade drain is horizontal step cascade drain provided at short length for each step.

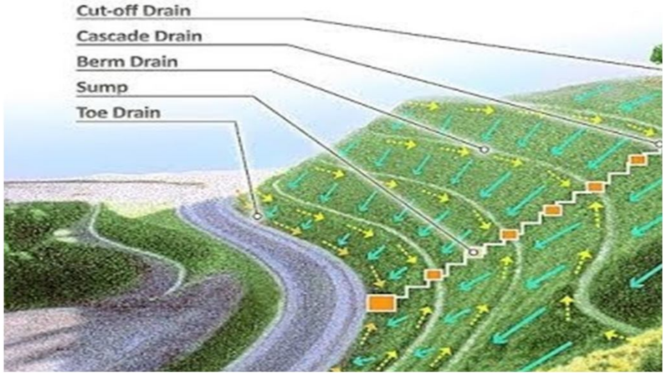

Fig 10: Cascade Drains

VI. CONSERVATION OF RAINWATER

Development of building sites generally leads to an increase of impermeable areas that can significantly increase the amount of surface water runoff to be dealt with the approach to disposal of surface water from buildings and hard surfaces clearly needs to be considered at the earliest stage in the design and development process.

Every building should be provided with a drainage system to remove rainwater might accumulate without causing damage to the structure or endangering the health and safety of people in and around the building where gutters and rainwater pipes are used, they should be constructed and installed in accordance with the recommendation.

A. Eave Drop System

This system allow rainwater to drop freely to the ground where these are used they should be designed taking into account the following-

1) The existing groundwater level and ground infiltration capacity. The protection of fabric of the building from ingress of water caused by water splashing on the wall.
2) The need to prevent water from entering doorways and windows.
3) The need to protect persons from falling eater when around the building.

B. Conservation at Regional Level

Paved surface drainage systems should be designed, constructed and installed by

1) Incorporating SUD system.
2) Using traditional piped drainage systems.

Surface water discharged from a building and a hard surface within a curtilage of a building should be carried to a point of disposal that will not endanger the building.

Discharge from soakaway should not endanger the stability of the building. Damage to foundations is likely to occur where discharge is too close to the building and it is sensible to ensure that any water bearing strata direct water away from the building.

C. Sustainable Urban Drainage Systems

Sustainable urban drainage (SUD) focuses decisions about drainage on the environment and people. The concept takes account of the quantity and quality of surface water runoff and the amenity value of surface water in the urban environment.

The variety of design options available allows designers and planners to consider local land use, land take, future management and needs of local people. SUD system is a management train that allows for a range of components to be incorporated for control or management of surface water such as;

1) *Source Control:* Control of runoff at or very near its source by components including soakways, other infiltration methods, green roofs or permeable surfaces.
2) *Site Control:* Management of surface water within a building site by components including large soak ways , infiltration systems or detention basins.
3) *Regional Control:* Management of surface water from building sites by components including balancing ponds and wetlands.

D. Modification in Drainage System

For this, we have taken a case study of Melbourne city. From that study we studied in detail and found out how to modify the drainage system.

Instead of discharging stormwater directly into the river, stormwater is diverted from the road drains into a diversion weir. The weir collects when water is allowed to pose before the pump into the primary storage tank. Weir contains special valves that allow excess stormwater flow into sewer drain for discharge into the river and also preventing salty water from entering into drain. Then water is passed through the primary storage tank.

This water tank consists of two compartments of underground storage tanks. First tank is the primary storage tank which consists of this untreated stormwater. A biofilter above the roofs of tanks removes phosphorus and nitrogen. Then clean water transferred to the second tank and transferred to gardening or industrial purposes.

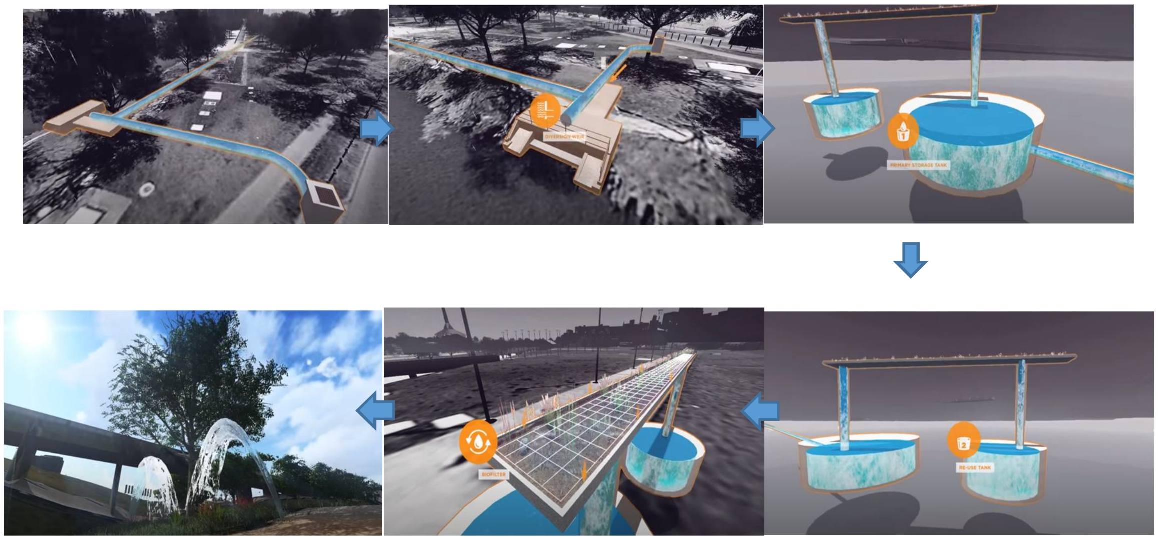

Fig 11. :-Schematic diagram of modifications made in drainage system.

VII. CONCLUSION

The above proposed system cares for easy and transitional change in the system and incorporates all the changes required in the system completely. If applied it will surely be fruitful and result oriented. It caters the demand of the problem and also maintains less infrastructure development to save cost. It also wastes less water thus it is environment friendly.

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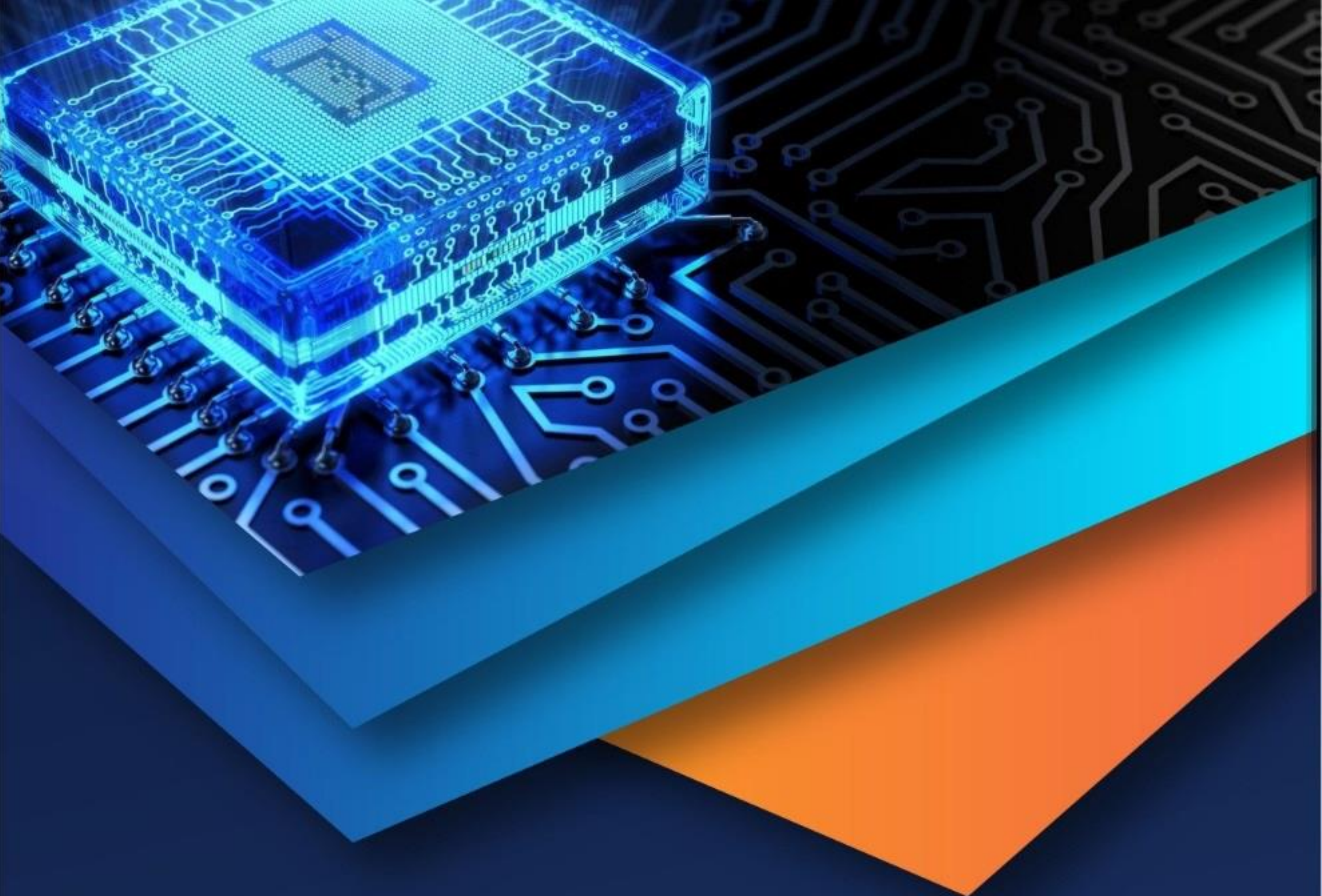

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