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Research Article

INTEGRATED DRAINAGE DESIGN USING GIS TECHNIQUE OF GONDIA CITY, MAHARASHTRA, INDIA

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ABSTRACT

The present paper aims at developing an efficient drainage system which would cater to the needs of people of Gondia city. Gondia city has seen rapid growth of construction in past two decades and with these changes, several problems of drainage have emerged. Future growth in population must also be considered and a drainage system is greatly required in the city to cater to the present and future demands. As study area is susceptible to high rainfall, the drainage system should also be designed to collect storm water runoff from roadway surface and right of way and convey it along and through right of way and discharge it to an adequate receiving body without causing adverse on or off site impact. In the present study the drainage system is designed as a combined system, which will serve for both Dry Weather Flow and Storm Weather Flow. The contour plan of the Gondia city has been prepared to obtain topography and has been merged with location of streets and roads. The layout of Gondia city for sewer design and alignment has been proposed using GIS technique and the same has been extended for determination of storm water discharge using rational method.

INTRODUCTION

Gondia is a developing city of Maharashtra State with future possibilities. It has conventional and quite old open drainage system. It is comprised of storm water drains along road sides which collect the storm water and convey it to the larger drains carrying domestic, commercial, cottage-industrial waste and sewage. There is no proper waste water treatment facility available. The storm water drains have not been maintained therefore, there is a lot of infiltration of polluted storm water into groundwater as well. Also the storm drains prove ineffectual in rainy seasons and incidents of flooding take place. There is a great need for a proper drainage system. But the system should be designed keeping in mind the future needs. Here, Sustainable Drainage Systems (SuDS) can play a major role in providing a solution to tackle present drainage needs but is also expected to reduce future problems relating to pollution. Thus, the drainage system to be provided must be a combination of conventional drainage methods as well as modern SuDS techniques (Pandey, *et al*., 2014). In the present study, the flood prone potential zone of urban area of the Gondia city, the Gajanan colony is selected to propose the model design in the structured form of pilot project based on the concept of Sustainable Drainage Systems (SuDS) of wastewater and storm water discharge. Such a network of drainage pipeline shall minimize the causes of occurrence of urban floods and related perceived threat to cause subsurface water pollution of the identified area (Fryd & Jensen, 2012).

The concept behind the application of SuDS in the context is to replicate natural systems using cost effective solutions with low environmental impact to drain away waste and surface water run-off through collection, storage, and treatment before allowing it to be released back into the environment i.e. into water courses (Krebs, & Larsen, 1997, Chocat, *et al*., 2007 and Larsen & Gujer, 1997). This is to counter the effects of

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conventional drainage systems that are prone to cause contamination of groundwater sources used for potable purpose. The SuDS at essence involve ease of application and management with requirement of little or no energy input (except from environmental sources such as sunlight, etc.), having resilience in use and being environment friendly as well as aesthetically attractive (Sharma,2008).

The use of SuDS within existing urban environments is limited due to a lack of available space and relatively larger land requirement (Stewart and Hytiris, 2008). However, SuDS such as permeable pavements and green roofs can be integrated in existing densely urbanized environments (Acks, *et al*. 2006 and Alsup, *et al*. 2010). The private residents and business community concerned must be prepared to incorporate such measures to existing infrastructure where there are high cost implications and relatively little projected benefits to the user (Katpatal and Mane, 2009).

In many parts of globe, SuDS is used with its main focus on maintaining good public health, protecting valuable water resources from pollution and preserving biological diversity and natural resources for future needs (Willems, *et al*.,2012, Hellström, *et al*., 2000 & Butler. and Parkinson, 1997). In Australia, the term Water Sensitive Urban Design (WSUD) was proposed as a catchment-wide approach of which SUDS is a part and mainly refers to sustainably integrate urban water management into city landscape to minimize environmental degradation and achieve harmony between water and the urban environment (Roy, *et al*., 2008 & Sharma, *et al*., 2008). SUDS is known as Low-Impact Development (LID) in the United States and Canada, which describes an approach promoting the interaction of natural processes with the urban environment to preserve and recreate ecosystems for water management (Coffman, *et al*., 1998). LID puts the emphasis on conserving and using natural features in combination with small-scale hydrological controls to mitigate adverse impacts of urbanization (County, 1999, Dietz, 2007 and Elliott & Trowsdale, 2007).

The theoretical and practical efficiency of SuDS in controlling the storage and discharge of surface water runoff to the underlying soil or receiving watercourse is generally known (Stewart. and Hytiris, 2008). However, constant monitoring after their inception must be carried out in order to reduce the likelihood of blockage or failure of the system, which could invariably lead to an increased value addition in the infrastructure network for existing watercourses.

Due to lack of proper drainage facilities, all the roads remain inundated during rainy season leading to water stagnation in the low lying regions of this area. The water on roads causes floods and traffic problems. Also, the polluted run-off water enters into water supply systems causing pollution. The present work attempts to provide a workable solution to the problem by streamlining the drainage system network applying SuDS techniques. The drainage system is proposed to be designed as a combined system, which will serve for water flow during both Dry and monsoon season conditions. The contour plan of the Gondia city has been prepared to obtain topography and has been merged with location of streets and roads. The layout for the arrangement of sewer alignment has been prepared as shown below. Determination of storm water discharge is proposed to be made with the help of rational method of sewage design (www.lmnoeng.com/ www.lmnoeng.com).

Study Area

The Gajanan Colony is located in the Gondia city along the Ring road. The area is bounded by the longitudes 80º11’34.2.28”E and 80º11’49.19”E and latitudes 21º28’21.15”N and 21º28’39.34”N. The Gajanan Colony is located in the Sector II of Gondia Municipal Council’s Proposed Sectional Development Plan. This sector includes 194 hectare land, partly from Mouza-Kudwa, Gondia (Buzurg) and Katangi Kala. In this sector, 108 hectare is developed land, which forms more than 50% of the sector area. Out of total developed area, 61 hectare land is under residential use, it is about 56% of total developed area. About 20 hectare area is under roads, which includes newly developed 80 m wide bypass road connected to Tirora-Gondia-Balaghat highway.

This sector also shows haphazard residential development. The projected population of this sector could be by2025 is 22250 (Pandey, 2012). The Gajanan Colony covers an area of about 0.6 Km^2 as shown in satellite image in (Fig 1).

Figure 1 The Satellite image of the Gajanan colony in Gondia City (Courtesy: Google earth.com).

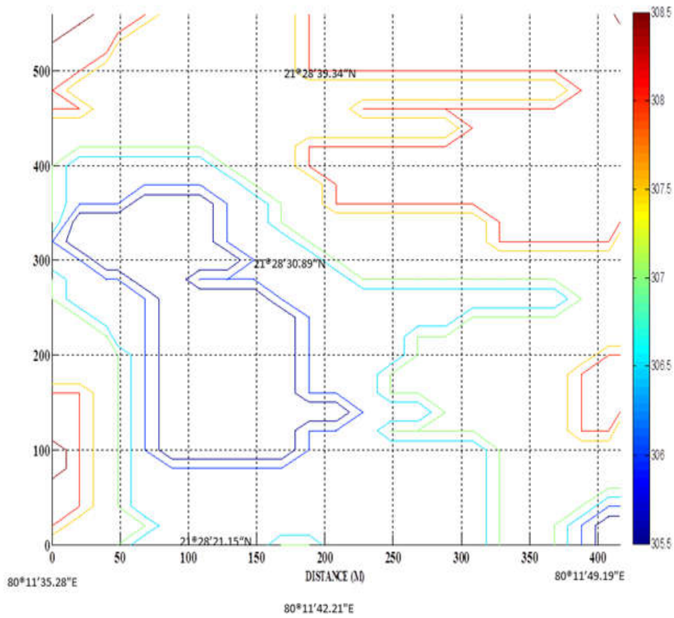

Figure 2 Contour map of the Gajanan Colony area after (Pandey, *et al*., 2015).

This area is a habitat for many people living and working in the Gondia city. Gajanan colony is located in the Gondia Municipal Council that comes under potentially annually flood affected area (Pandey, *et al*., 2015). This area has got developed very fast in the post 2000 period. During that time, it was not within the Gondia Municipal Council limits. As a result, random construction took place in that area. The maximum elevated level 308 m is situated in the north-western part of the study area and minimum elevation is 305 m in the south-west portion of the area as shown in the contour map in (Fig 2).

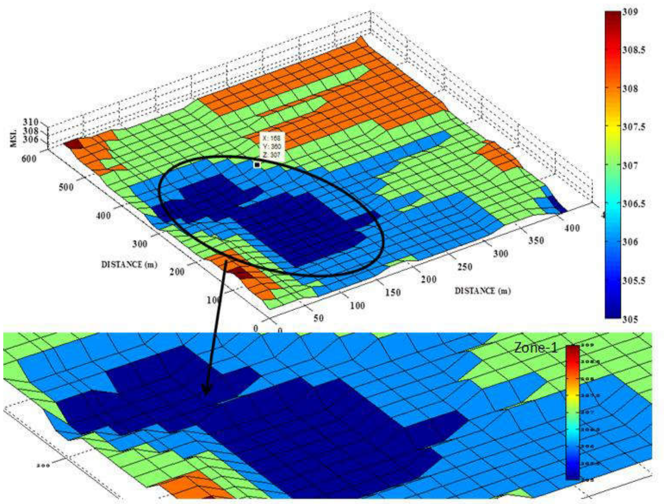

Figure 3 Digital Elevation Model of the Gajanan colony area after (Pandey, *et al*., 2015).

A bowl shaped structure is formed in the area due to which the water stays accumulated in one place and does not move out as shown in (Fig 2-3). There is no municipal drainage system present in the area. Excessive constructions in the depression region have led to encroachment of the unlined open drains around the houses (Pandey, *et al*., 2015). This has reduced their ability to drain the runoff water as shown in digital elevation model of Gajanan colony area in (Fig 3). This has resulted in blockage of natural drainage of the area leading to stagnation of the runoff water.

METHODOLOGY

The system formulated is not fully a SuDS exemplar, but is a combination of conventional drainage methods and SuDS methods. The design of drainage system is formulated with the aid of certain basic data that includes the following information:

Land use mapping: Identification of the existing and expected future uses of land.

Watershed mapping: Identification of topographic features, watershed boundaries, existing drainage patterns, and ground cover. Information sources included Google Earth, Google maps, aerial photography, or mapping available from local river authorities and other planning agencies.

The topographical features of Gondia City were studied using Google Earth, and a detailed contour map obtained with AutoCAD design software showing the ground elevations, is as indicated in (Fig 4). The map is on a scale of 1: 50000 cover an area 1808 Hectares and contour interval is 2 m. The general gradient of ground slope is from South-West to North-East. The highest elevation being 338 m above Mean Sea Level gradually dipping to the lowest elevation at 298 m above MSL, while the intermediate land area undergoes a variety of undulations in elevation, making it difficult to lay down a simple drainage system.

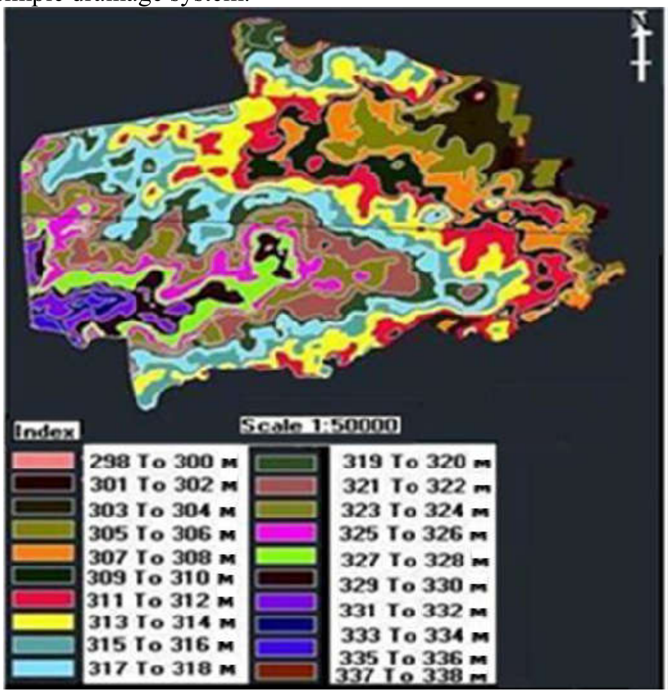

Figure 4 Two meters interval Contour map of Gondia city.

Description of Existing Drainage Facilities

Information about the existing drainage facilities was unavailable from local authorities and zoning bodies. So the existing natural drainage patterns were studied using Google Earth image and are as shown in (Fig 5). There is general trend of slope observed from central portion to north and south ward direction of the city meeting towards east.

Figure 5 Existing natural drainage system of Gondia city (Courtesy: Google earth)

Determination of Design Discharge

Design discharge of the area has been analyzed using rational formula as shown in equation number 1.

Storm Water Flow:

Rational Formula: $Q = 28\ A.I.R$ (1).

Where, Q= Design Discharge

I= Impermeability Factor

A= Catchment Area in Hectares

Runoff Coefficient

Runoff Coefficient for the city is calculated using the data given in the land use distribution and impermeability factors (Kuichling, 1889) as indicated in Table 1.

Table 1 Impermeability factor computations of Gondia city.

No.	Land Use	Area (in Hectares)	Impermeability Factor
1.	Residential	308.00	.80
2.	Commercial	32.50	.85
3.	Industrial	34.00	.90
5.	Public Areas	70.00	.85
6.	Public Utility	6.25	.90
7.	Transport a. Roads b. Railways	 155.00 91.25	 .50 .30
8.	Gardens, Playground	20.45	.20
9.	Water Bodies	39.00	00
10.	Agricultural	485.50	.10
11.	Vacant & Barren land	566.05	.10
		TOTAL: 1808	

Avg. Impermeability Factor $= A_1I_1 + A_2I_2 + \ldots\ldots A_nI_n / A1 + A_2 + \ldots A_{n\ldots\ldots} = 0.32$ (2)

Rainfall Intensity

The Gondia Region mainly receives rainfall during the months of June, July, August and September. The area under Gondia municipality region received an average rainfall of 1295.53 mm during last five decades (Pandey *et al.*, 2015). Thus, the rainfall intensity is computed to be 1.306 cm/hr. Sector-wise distribution of storm water flow during monsoon is shown in Table 2.

Table 2 Sector-wise distribution of Storm Water Discharge.

Sector	I	II	III	IV	V	VI	VII	VIII	IX	X
Population (Pandey, 2012)	25277	18385	25120	8431	13847	9012	14741	18934	7348	15904
Discharge (in Cumecs)	6.53	5.008	4.98	1.88	3.898	2.73	3.30	6.06	1.18	11.07

Dry Weather Flow

Sector-wise population of Gondia City is taken from the available data (Pandey, 2012). Considering daily water supply of 13 MLD to the city, 80% of this amount is taken as total sewage generated. Sector-wise distribution of dry weather sewage water flow is given below in the Table 3.

Table 3 Sector-wise distribution of Dry Weather water Flow.

Sector	I	II	III	IV	V	VI	VII	VIII	IX	X
Discharge (in Cumecs)	0.032	0.023	0.031	0.011	0.017	0.011	0.018	0.024	0.0092	0.020

The Catchment area was divided into ten sectors for the purpose of determination of diameter of Main Trunk Line. Diameters of the Main Trunk Lines is calculated using Manning's Nomogram (n=0.013) of Cast Iron Pipes (which is widely used for determining the diameter as well as non-silting and non-scouring velocity in sewage pipes running full) is as indicated in Table 4.

Table 4 Recommended diameters for Main Trunk Sewers Drain.

Sectors	Storm water flow	Dry Weather Flow	Design Discharge (DWF+WWF)	Approx. Diameter of Pipe (in M)
I	6.53	.032	13.124	2
II	5.00	.023	10.046	1.7
III	4.98	.031	10.58	1.6
IV	1.88	.011	3.782	1.0
V	3.898	.017	3.93	1.5
VI	2.73	.011	5.482	1.2
VII	3.3	.018	6.603	1.4
VIII	6.06	.024	12.164	1.8
IX	1.18	.0092	2.378	.60
X	11.07	.020	22.54	2.5

The Catchment area has been divided into two zones namely North zone & South Zone for the purpose of determination of diameter of Main Trunk Line as show in (Fig 6). The population in North and South zone was calculated using data available (Pandey, 2012). The details of the area covered and the corresponding population is as displayed in Table 5.

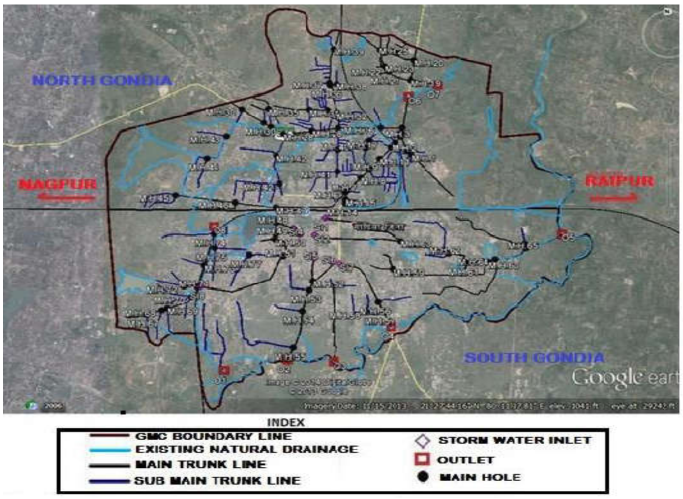

Figure 6 Proposed storm water flow network of drainage system of Gondia city shown in blue (Sub drain) and black (Main drain) color.

The total water supply requirement to the Gondia city is assumed to be 26 MLD by 2051 (Punmia, *et al.*, 1990)**.** The sewage generated has been taken as 80% of the total water supplied per day. Diameter of the Main Trunk Line is calculated using Hazen William's Nomogram of Cast Iron Pipes as shown below. This is widely used for determining the diameter as well as non-silting and non-scouring velocity in sewage pipes running full. Figure 6 depict the integrated network of SuDS proposed for entire Gondia city. The layout of the proposed network of SuDS is designed considering the natural drainage pattern of the city.

Table 5 Recommended Diameter for Main Trunk Sewers for future.

Zones	Projected population in 2051	Area Covered in Hectares	Per-Capita Demand	Sewage generated in liters /day (80% of per capita)	Average Sewage in Cumecs	Maximum Sewage (2*Average Sewage) in Cumecs	Diameter of Main Trunk Line in meters
North	128245	2477	12	16928340	0.916	0.392	0.8
South	172655	886	14	22790460	0.264	0.528	1.0
Total	300900	3363	26	39718800	1.18	0.92	

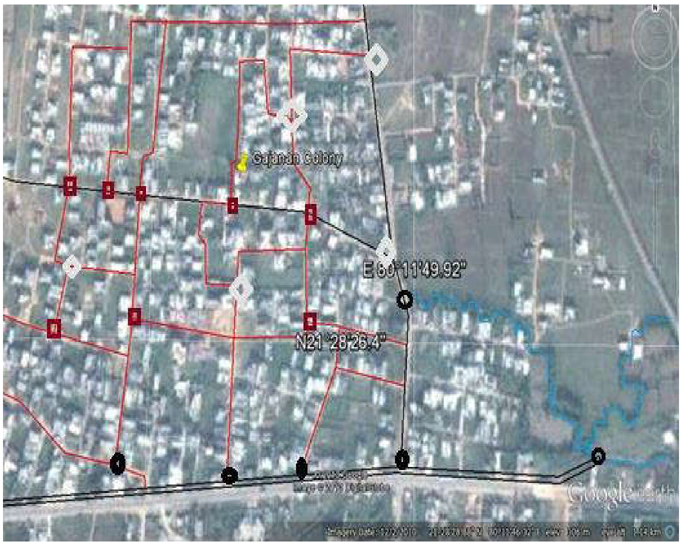

Figure 7 Proposed drainage network of Gajanan Colony is showed in red and black

(Fig 7) depicts the proposed drainage pattern for Gajanan Colony of Gondia city to mitigate the urban storm surge problem faced by it every year.

Recommendations

The prime causes of floods in the Gondia city might be related to expansion of the urban limits into the flood prone zones which have been developed as discussed above. The anthropogenic activity seems to be poorly planned, with unplanned drainage channel designs and not best of the management practices being observed in the maintenance which leads to the flood menace.

As a part of the pilot project, the urban site Gajanan colony within Gondia Municipal Council having an area of 0.6 Km^2 was identified for the study. Knowing the cause of floods in the region is anthropogenic, through the remote sensing and related digital elevation modeling images techniques, the SUDS model has been proposed for the sustainable integrated drainage channel design and management. The calculated drainage pipeline diameters are proposed for the management of waste water flow during both the storm water monsoon and dry season conditions. Anthropogenic cause of floods can be minimized with active human intervention, with the application of SuDS.

The drainage pattern of Gondia city has to be upgraded. Proper planning according to growing population is required for the construction and maintenance of an underground drainage system. This will enable a better sewage clearance and drainage of heavy runoff of rainwater. This will also minimize the effects of water logging in certain areas like Gajanan Colony and keep the city away from the menace of floods and its perceived impact to cause ground water pollution. The probable action plan can be the construction of central drainage system parallel to the Ring road. This will in turn help in drainage of bulk amount of water from the surrounding areas on both the sides of the road. The network of sub drains should be constructed in the area in between different houses. Thus these sub-drains should be integrated with central drainage. The unlined open drainage system should be duly lined and cleaned regularly to prevent blockage. Proper planning of the developing areas and strict imposition of rules by the town planning department is very important to tackle this sort of situation. Thus the problem of flooding and water logging can be eradicated from the area. From the GIS study, it was also found out that another option is to develop filter strips, ponds, basins, swales etc. near the bank of the river Pangoli since wastewater from the agricultural land pollutes the river directly.

CONCLUSION

It is very difficult to establish SuDs in an urbanized city but Gondia City can be easily incorporated in a proper Suds system. After studying land-use pattern for the city using GIS and remote sensing it was found out that there is space available in the city to develop a new drainage pattern. Suds techniques such as permeable pavements can be used in areas where other methods are not effective or are difficult to provide. Therefore, it is mandatory to follow an integrated approach where engineers and planners must develop SuDs along with the existing drainage patterns in the city. From the GIS study it was also found out that another option is to develop filter strips, ponds, basins, swales etc. near the bank of the river Pangoli since wastewater from the agricultural land pollutes the river directly.

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