Geographic Information System (GIS) based Approach in Delineation of Efficient Natural Flow Routes for Drainage Plan of a Municipality

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Abstract

The purpose of the drainage plan is to make an assessment of the present drainage facilities and the scope for future drainage network development. For the drainage master plan, it is very important to consider the delineation of natural flow routes but most of the cases it is not considered at municipal drainage master plan. The aim of the delineation of efficient natural flow routes for drainage master plan of a municipality is to ensure that the master plan will provide direction on drainage system that will serve to convey runoff in natural ways to increase the optimum level of drainage system. In this study, Geographic Information Systems (GIS) is used to create a Digital Elevation Model (DEM) data or contour data from the point height data. The DEM or contour data is then processed using the ArcGIS software to determine heavily accumulating flow routes. By following this approach runoff natural flow routes from contour lines is determinable here on a GIS platform. This study also tries to show the contradictions between natural flow routes and proposed drainage master plan. This approach is applicable to eliminate the water logging and to make an efficient drainage network that will be cost effective to the municipal budget. This will also be helpful in designing drainage master plan of the municipality.

Keywords: Geographic Information Systems (GIS), Drainage network, Digital Elevation Model (DEM), Flow Accumulation, Flow Direction and Natural Flow Route

1. Introduction

Drainage network is an important element for any community. The artificial and natural drainage helps to remove sullage and storm water from surface and prevents many problems such as water logging, environmental pollution etc. So it has importance in the natural consequence as well as in our daily life. Moreover it is an important utility service for a community. Drainage can be defined as the removable of unwanted water from human settlement. Such unwanted water can include storm runoff and flood water from seasonal rains, marsh or pond water in low lying areas, and the used domestic waste water (sullage) of the community. Drainage systems are needed in developed urban areas because of the interaction between human activity and the natural water cycle. This interaction has two main forms: the abstraction of water from the natural cycle to provide a water supply for human life and the covering of land with impermeable surfaces that divert rainwater away from the local natural system of drainage (Butler and Davis, 2004). These two types of interaction give rise to two types of water that require drainage. Bangladesh is experiencing environmental degradation due to rapid urbanization, increase in population, and industrialization. The process of urbanization is linked with the economic development, which makes an increasingly higher contribution of the national economy. However, when the growth of urban population takes place at an exceptionally rapid rate,

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most cities and towns are unable to cope with changing situations due to their internal resources constraints and management limitations (Bari and Hasan, 2001). Urbanization demands modernization of existing drainage systems in economical way. The economics can be achieved only if drainage pattern follows natural streams. Drainage network efficiency in an environment is complex in nature. This requires adequate experience of the planning and appropriate data. Geographical information system (GIS) is one of such tool which can be used in general way to many complex problems especially when dealing with natural flow routes related problems.

2. Objectives of the Research

The objectives of this study are-

To delineate efficient natural flow routes of study area using topographic data.

To show a comparison between proposed drainage master plan and the delineated efficient natural flow routes of the study area and

To provide some recommendations in drainage system with efficient natural flaw routes in municipal level.

3. Some Conceptual Issues

3.1 Drainage

The drainage means “the removable of unwanted water from human settlement.” Such unwanted water can include storm runoff and flood water from seasonal rains, marsh or pond water in low lying areas, and the used domestic water (sullage) of the community. A comprehensive drainage study requires topographic, hydro-meteorological (rainfall and evaporation) and hydrometric (discharge and water level) data. The topographic data is also important to develop layouts and estimation of earthwork for the proposed road and drainage channel (Modern Civilization, nd.).

3.2 Need of Drainage

Drainage systems are needed in developed urban areas because of the interaction between human activity and the natural water cycle. This interaction has two main forms: the abstraction of water from the natural cycle to provide a water supply for human life and the covering of land with impermeable surfaces that divert rainwater away from the local natural system of drainage.

The second type of water requiring drainage, storm water, is rainwater (or water resulting from any form of precipitation) that has fallen on a built-up area. In developed catchments, direct runoff can increase to more than 80 percent of the rainfall volume. At the same time, because paved surfaces may be less rough than natural surfaces, water may travel over them faster and as a result runoff will reach the receiving watercourses more quickly. The flow rates in the receiving waters are therefore much more sensitive to rainfall intensity and volume than those in undeveloped catchments. Volume and rates of runoff both increase significantly after development. Peak flow rates can increase by a factor of up to ten, which means that streams and rivers have to cope with larger and often sudden runoff flows. It also means that drainage is needed to reduce flood risk within the developed areas. If storm water were not drained properly, it would cause inconvenience, drainage, flooding and further health risks (Modern Civilization, nd.).

3.3 GIS as a Tool for Drainage Data Generation

Urban Planners traditionally use aspect type approach of contour interpretation to determine routes to locate drainages in designing urban layouts. Arrows representing water flow direction can be drawn perpendicular to each contour, in the direction of the steepest descent.

This would be very laborious and error prone over large areas. A drainage route is a linear connection of land units that accumulate the most runoff in an area. Quantity of accumulation of runoff is determinable on a spread sheet when the sub-catchment and the area size is determined on a GIS platform.

Recently drainage areas have been delineated automatically using digital elevation models of the land-surfaces on GIS platforms. A digital elevation model (DEM) is a grid of rectangular cells of unique elevation values representing the land surface. By determining how water flows from cell to cell, the set of cells whose drainage flows through the cell at the outlet point location can be identified, and thus the drainage area determined.

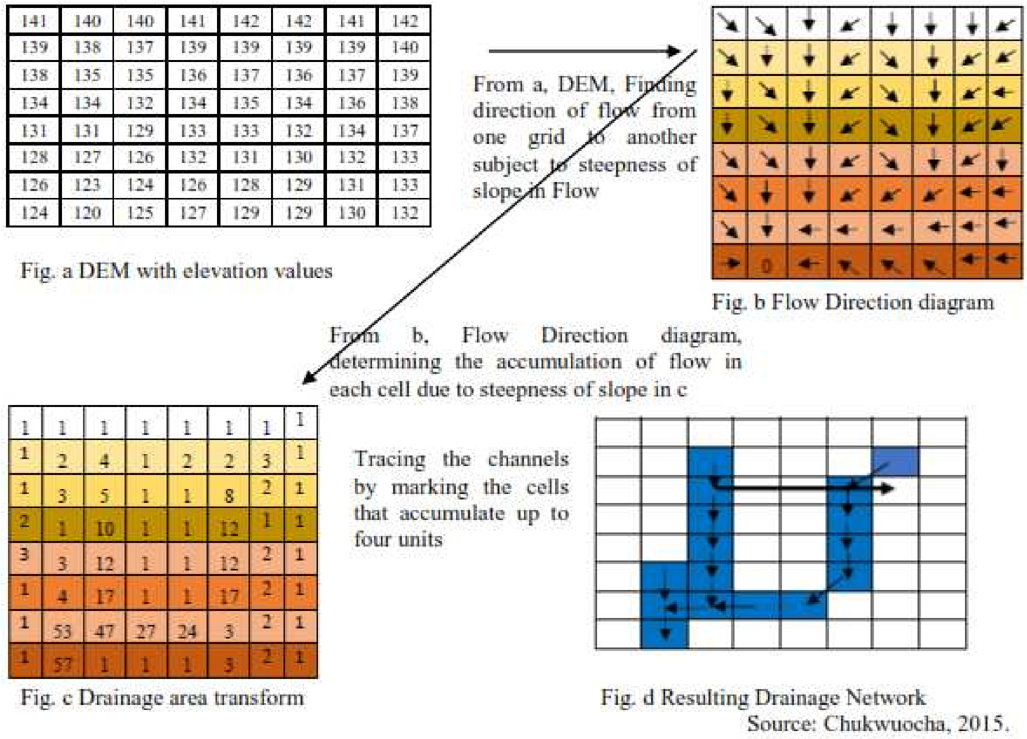


Figure 1: Concept of the "hydrological approach" of delineating drainage network from a DEM

Of all the possible methods used in GIS based delineation of hydrologic features at present, the most commonly used method appears to be the so-called "hydrological approach" proposed by Mark (1984). In this method, the "drainage area" of each DEM elevation grid (i.e., the number of cells that drain into a cell of interest) is first determined by climbing recursively through the DEM (Figures 1a and 1b). This process results in a matrix, called the "drainage area transform" (Figure 1c), that contains the drainage areas for all the grids in the DEM. The information in the drainage area transform is then used to trace the "channel pixels," as identified by those grids with large drainage areas. Channels are recursively followed upstream until there is no more point that exceeds a minimum threshold (Figure 1d). Once the drainage network has been delineated, ridges may be delineated either by gray-scale thinning of all non-channel pixels or by tracing the boundaries of the catchment area (Chukwuocha, 2015).

3.4 Flow Accumulation: Drainage Delineation

Once we have a raster that indicates flow direction, a number of other interesting and useful calculations are possible. In particular, we can determine the locations of all the linear bodies of water, and can determine, from slope and elevation, those areas where water may accumulate during times of intense precipitation. This is accomplished with the ArcToolbox Flow Accumulation tool. Basically, the value in each cell in the resulting raster contains the sum of the amount of water that has fallen on all the raster cells upstream from it.

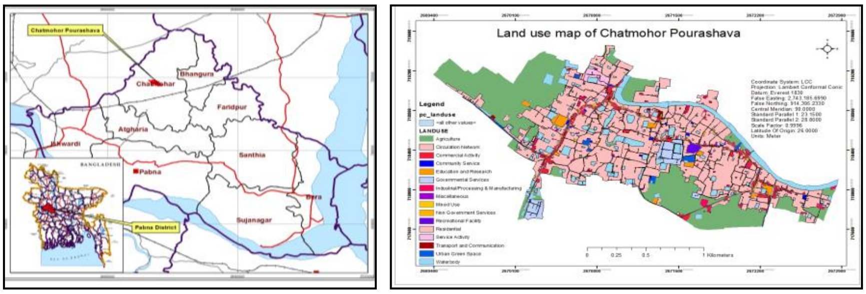
The intent is to simulate the flow, or potential flow, of water to form creeks, streams, and rivers. If each cell is presumed to have one unit of water (say, an inch in depth) to contribute—under a condition of "uniform rainfall," we can think of the number in a given cell as the number of cells upstream from that cell (Kennedy, 2013).

4. Study Area

Chatmohor is a C-category Pourashava with an area of 2.97 sq. km (734.33 acre) that was established in 1997 with 9 wards following the Local Government (Pourashava) Act, 1977. Chatmohor Pourashava is bounded on the north by Tarash Upazilas of Pabna District, on the east by Bhangura and Faridpur Upazila of Pabna District, on the south by Atgharia Upazila of Pabna District and on the west by Baraigram and Lalpur Upazilas of Natore District. The location of Chatmohor within Pabna District is shown in figure 2.

Chatmohor Pourashava is the urban center in the Chatmohor Upazila. It is located between 24°06´ and 24°21´ north latitudes and between 89°12´ and 89°24´ east longitudes. Pabna region is characterized by high and low lands.

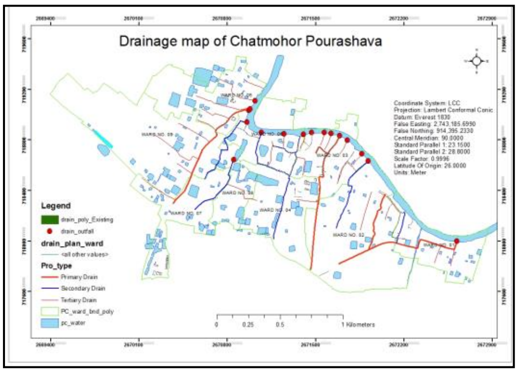
Chatmohor is located within the flood plain of Baral River. During the rainy season, these Moribund Rivers act as excellent drainage channels draining a large volume of water and have a strong current (LGED, 2015).



Source: LGED, 2015 and developed by authors, 2020
Fig 2: Map of Study Area.

4.1 Drainage Condition of the Study Area

Majority of the population at Chatmohor Pourashava is deprived of drainage facility. Uncollected waste is washed out into the roadside drains and natural canals. Blockage of drains by solid waste reduces the carrying capacity of drains and natural canals and become a source of pollution. Pourashava has very limited resources to clean the drains. It has been observed that in some areas, domestic sewage conveys directly to the water channels. Water logging is a problem at some parts of Chatmohor Pourashava, causing water logging for 5-7 days each time a heavy rainfall occurs between June and November every year.



Source: LGED, 2015 and developed by authors, 2020
Fig 3: Map of existing and proposed drainage network of Chatmohor Pourashava

4.2 Existing Drainage System/Network

The drainage system of the Chatmohor Pourashava has been classified into three categories: (i) unlined natural canals and khals acting as primary drains, (ii) beels playing important role in acting as retention ponds and (iii) brick masonry secondary and tertiary drains and earthen shallow secondary drains.

4.3 Natural Drainage System

The natural drainage network is composed with 179 water bodies in Chatmohor Pourashava out of which 87are ponds and 89 are ditches and 01 khals. Total area devoted to water bodies in Chatmohor Pourashava is around 90.27 acres including river. It can also be seen that the ward 1 possess highest area for water bodies. In this ward there are 7 ponds and 11 ditches but river portion is bigger than any other ward (LGED, 2015). The existing one khals and river are covered the entire pourashava of natural drainage system. There are linkages between natural and man-made drainage system. But how much effective and active the linkage is with the poorly maintained man-made drains is a question. Almost half of the depth of the man-made drain is filled with solid garbage's; as a result, the channel is not properly functioning.

4.4 Man-made Drains

In this Pourashava there is 5.62 km drain. Uncovered drains are mostly in existence with poor condition. Within the Pourashava total 5.11 km brick drains so far constructed by DPHE. The table indicates that there is limited amount of drainage in Chatmohor Pourashava.

Table 1: Ward-Wise drainage Network of Chatmohor Pourashava

Ward No	Length (km)		
	Pucca		**Status**
1	0.662	12.93%	Uncovered
2	0.273	5.33%	Uncovered
3	1.175	22.95%	Uncovered
4	0.574	11.21%	Uncovered
5	0.593	11.58%	Uncovered
6	1.162	22.70%	Uncovered
7	0.678	13.24%	Uncovered
8	0	0%	Uncovered
9	0.003	0.06%	Uncovered
Total	5.119	100.00%	Uncovered

Source: LGED, 2015**.**

5. Proposal for Improvement of the Existing Drainage Networks

There is 5.11 km existing main khals in Chatmohor Pourashava. This total 01 khals will be served as primary drain. Based on this primary drain, drainage network system of Chatmohor Pourashava will be established. In Chatmohor Pourashava master plan LGED has proposed total 4.41 km secondary drain and 5.82 km tertiary drain in drainage development plan. Fig 3 shows the drainage network Plan of Chatmohor Pourashava.

Table 2: List of Drains for Proposed Improvement

Type of Drain	Length in M	Length in Km	%
Secondary Drain	4411.75	4.41	43.12
Tertiary Drain	5820.54	5.82	56.88
Total	10232.29	10.23	100.00

Source: LGED, 2015.

6. Methods for Delineating Natural Flow Routes in Study Area

The existing Topographic data is used here to create a contour map and then by using the topographic data or the contour data, a Digital Elevation Model (DEM) of the project area on a GIS platform is produced for the purpose. And finally by GIS processing delineate drainage routes on the map of the study area is created here by different GIS procedure.

6.1 Creation of the Digital Elevation Model

The topographic data were added as data into ArcGIS software. These topographic data which were geo referenced in ArcGIS using the Lambert Conformal Conic parameters of GCS_Everest_1830 coordinate datum. There were total 9084 points data in the Topographic shape file of the study area. These points indicating the RL values of the study area.

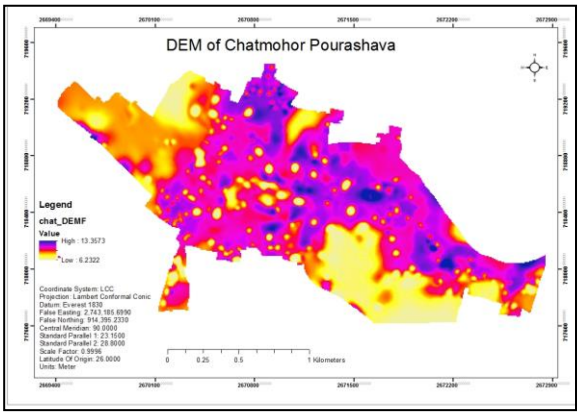
The contours of the entire project area were used to create the Digital Elevation Model (DEM) in ArcGIS. Maximum spot level of Chatmohor Pourashava is 12.9 m located at ward no 3 and lowest point is recorded as 5.24 m located at ward no 4. Average elevation of Chatmohor Pourashava area is derived as 10.67 m and the standard deviation is 0.77.

Table 3: Land Use Category with Spot Heights (mPWD) in Chatmohor Pourashava

Landuse	**Min**	**Max**	**Mean**
Agriculture	11.70	8.82	10.13
Circulation network	10.19	15.97	11.64
Commercial Activity	12.69	9.28	11.14
Community Service	12.78	11.10	11.49
Education and Research	12.01	9.30	10.87
Governmental Services	11.94	9.41	11.02
Industrial/Processing & Manufacturing	11.81	9.30	10.75
Miscellaneous	11.73	10.01	10.98
Mixed Use	12.59	11.10	11.56
Non Government Services	11.43	10.01	10.92
Recreational Facility	11.99	11.31	11.43
Residential	12.90	9.00	11.16
Transport and Communication	11.90	11.04	11.51
Urban Green Space	12.49	9.60	10.90
Waterbody	11.34	5.24	8.93

Source: LGED, 2015 and Topographic Survey in Chatmohor Pourashava.

Then the DEM is clipped by the study area boundary of Chatmohor Pourashava.



Source: LGED, 2015 and developed by authors, 2020.

Fig 4: Map of the Digital Elevation Model (DEM) of Chatmohor Pourashava

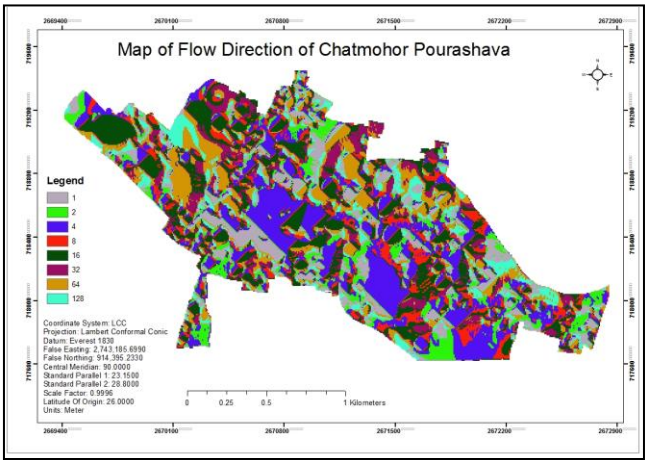
The value of each DEM pixel is a generalization of all elevations possible to occur in the DEM cell, each cell in this case is of size of 7.3024m x 7.3024m (53.33 Sq. m), with a column of 471 and rows of 251.

6.2 Flow Direction of Study Area

The value in any given cell of the flow direction grid indicates the direction of the steepest descent from that cell to one of its neighboring cells using the eight direction pour point (D8) method. The output of the Flow Direction tool is an integer raster whose values range from 1 to 255. The values for each direction from the center are:

32	64	128
16		1
8	4	2

For example, if the direction of steepest drop was to the left of the current processing cell, its flow direction would be coded as 16. If a cell is lower than its eight neighbors that cell is given the value of its lowest neighbor, and flow is defined toward this cell. If multiple neighbors have the lowest value, the cell is still given this value. This is used to filter out one cell sinks, which are considered noise. After the process is complete, a flow direction grid with cells having one of the eight flow direction values (1,2,4,8,16,32,64,128) is added to the map document (Alam and Khan, 2014).

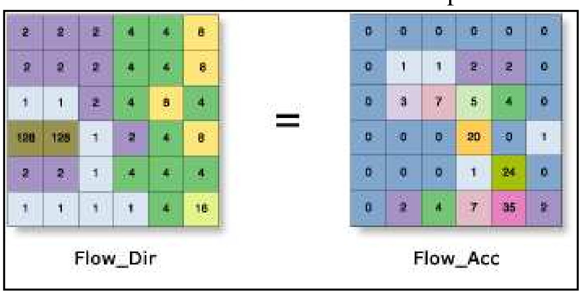


Source: Developed by authors, 2020

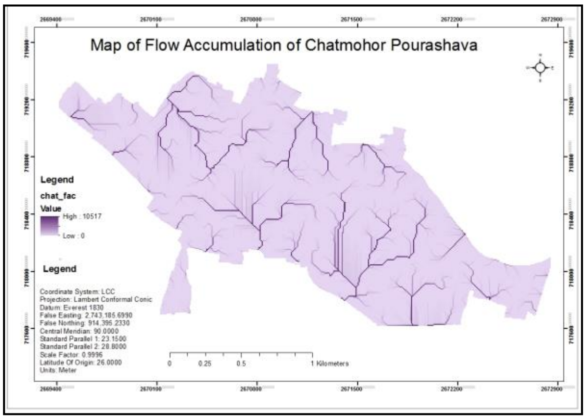
Fig 5: Map of Flow Direction of Chatmohor Pourashava

6.3 Flow Accumulation of Study Area

Flow Accumulation creates a raster of accumulated flow into each cell. A weight factor can optionally be applied. The result of Flow Accumulation is a raster of accumulated flow to each cell, as determined by accumulating the weight for all cells that flow into each downslope cell.



Cells of undefined flow direction will only receive flow; they will not contribute to any downstream flow. A cell is considered to have an undefined flow direction if its value in the flow direction raster is anything other than 1, 2, 4, 8, 16, 32, 64, or 128. The accumulated flow is based on the number of cells flowing into each cell in the output raster. The current processing cell is not considered in this accumulation. Output cells with a high flow accumulation are areas of concentrated flow and can be used to identify stream channels.



Source: Developed by authors, 2020

Fig 6: Map of Flow Accumulation of the Chatmohor Pourashava

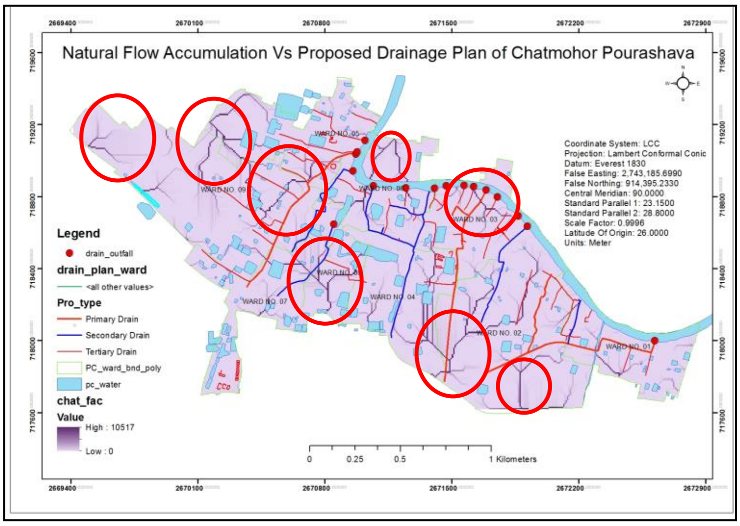
The process of delineation of the natural flow routes in study area is illustrated in Fig 6. Each cell of the area accumulates water that rains directly on it plus the runoff that flows from other cells through it. The number of cells upstream that accumulate into a cell of interest is the value of that cell in the flow accumulation. In figure 6 we can see the flow accumulation channels in Chatmohor pourashava. The dark violate portions are representing highest accumulation channel and the light violate portion representing low accumulation.

7. Results and Comparative Discussion

Urban flooding and water logging can be mitigate by efficient drainage network. Efficiency of drainage depends on proper sloping, location and size, etc. Naturally land areas have natural flow routes. The natural flow routes should be considered as primary drain for an urban area. The other drainages like secondary and tertiary drain must be linked with the natural flow routes (which should be considered as primary drain) for efficient and cost effective drainage system of an area.

The map of the delineated natural flow routes was superimposed on the map of the study area to create Fig 7. It presents the main express routes with some sizeable drainages shown in red lines. The streams and rivers are shown in sky color. While the dislocations of the roadside drainages from the delineated natural routes are obvious, the determination of the efficiency or otherwise of the city drainage system was ascertained by visiting the primary natural flow routes to determine the efficiency of the primary level drainages. The greater part of the drainages of the study area were constructed alongside the roads.

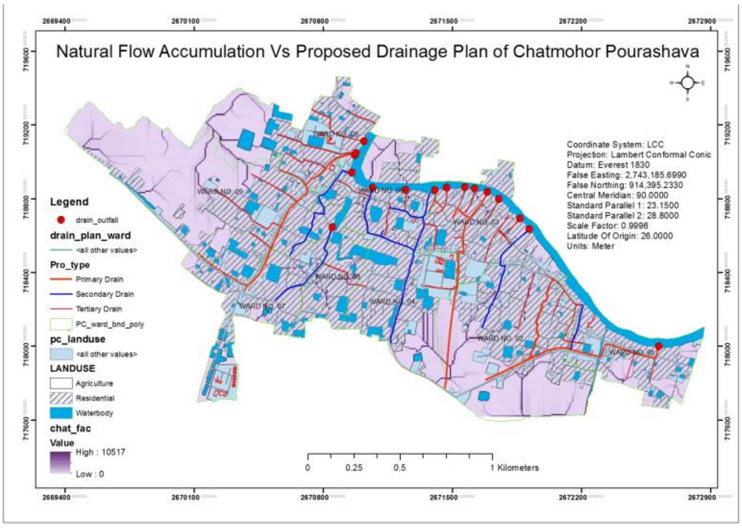
The red mark areas in figure 7, is representing contradictions between natural flow routes and the proposed drainage plan of the study area. In most of the cases the primary and secondary drains are not following the natural flow routes. Primary drains has been prepared on high land rather considering natural flow routes.



Source: Developed by authors, 2020

Fig 7: Map of Natural Flow accumulation and Proposed Drainage Master Plan

The delineated natural flow routes of the study area were visited to determine the suitability of the constructed drainages. In figure 8 we can see that a number of the sites in the built up areas and there were no drainages constructed at the locations. In some cases houses have been constructed along the delineated natural flow routes. It was also observed that the routes are also blocked by roads and settlements constructed across the natural flow routes for raised elevations. This made the routes on the upstream side to hold back flow.



Source: Developed by authors, 2020

Fig 8: Map of Natural Flow accumulation and Proposed Drainage Master Plan

8. Recommendations

Topographically Chatmohor Pourashava is flat and gentle sloping. The natural topography of Pourashava area has already been changed for urbanization. The present trend of development like roads, drainage, bridge/culvert, housing and industrial estates and bazars will radically change the natural topography and land use pattern of the area. The agricultural area will be converted into urban and semi-urban area in near future.

The present green scenic beauty will disappear, water bodies will be lost and general slope will be diminished for earth cutting due to rapid urbanization. To mitigate urban flooding or water logging in urban areas the following measures could be taken by local authorities-

Making efficient and cost effective drainage design. Local government authorities should adopt GIS based approaches to determine efficient natural flows. If the authorities use natural flow streams in drain design it will be more cost effective rather using any other routes.

Authorities should prepare a good GIS data base and revise the topographic data after 5/10 years to revise drainage efficiency factors. Careful planning to minimize the change of topography.

Governments should ensure that the determined natural flow routes are marked on the ground both in urban and rural areas and even farmlands in municipal level.

Legislations should be enacted and people educated to stay off those routes for the inherent dangers of flooding the areas due to the routes being blocked by blockages erected along these drainage routes.

Make proper drainage network in new area considering the slope and local topographical condition.

Avoid water bodies during construction of roads, housing and industrial estates.

Preserve the natural greenery, ponds, khals and large water bodies.

Conserve water bodies from haphazard urban development.

Protect the ponds having area more than 0.25 acre as per regulatory framework of Master Plan.

Since natural drainage routes are actually routes eroded over time by runoff, the Geographic Information System based approach to mapping of natural drainage routes will lend itself of the study area.

9. Conclusion

This study has demonstrated efficient natural flow routes considering factors like location, alignment and slope using Geographic Information Systems. These factors relied completely on the use of Digital Elevation Model (DEM) of the area analyzed on a GIS platform. The DEM was derived from the RL value of the topographic points of the study area on a GIS platform. Using natural flow routes as primary drain or secondary drain could be an effective way for the municipalities to optimize the drainage system. This study will enable the local government authorities to incorporate GIS based approach in delineating natural flow routes more accurately and using the natural flow routes in their drainage plan.

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