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WATERSHED DELINEATION IN FLAT URBAN AREAS USING GIS TECHNIQUES

BY

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Abstract. The accurate determination of the catchments is still a challenge in the flat terrains of the urban areas even if this is a precondition for runoff modeling, hydrological modeling and water quality simulations. To aid in delineating of the contributing drainage areas across an entire city at the level of individual drain inlets, which were then aggregated to larger basins in an urban landscape, a workflow has been developed. The purpose of this paper is to delineate the regional storm watershed properties to perform a drainage analysis on a terrain model. Arc Hydro package has been utilized for this study because can reduce considerably the time-consuming processes as well as help to improve the reliability and resolution. The results of this study show that delineations of urban watersheds in flat areas can be possible even in lower resolution city models and provide high superiorly data if a complete database that reflects the reality will be utilized. Furthermore, a distinction has been made between the basins which drains to the surface waters and those that are draining to the sewerage network. The results can be easily used to study the pipe hydraulics for sewer systems and for future management planning.

Keywords: watershed delineation, stormwater network, digital terrain model, hydrology.

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1. Introduction

A watershed can be described as a natural geohydrological unit from where the water flows downhill to a common outlet point which is formed from streams, distributes to rivers, ponds or reservoirs (Datta *et al.*, 2022; Sowmya *et al.*, 2020). According to Karmaker *et al*. (2022), the rainwater drainage represents the main source of drinking water in the watersheds, and thus, they have an important role in conservation of the runoff water from different sources (Santiago-Collazo *et al*., 2019). Therefore, watershed analysis represents a mandatory process in the sustainable management of our natural resources. If the drainage areas and the flow paths networks are accurate correctly identified the adequate management of the stormwater runoff and water quality issues can be completely accomplished (Senior *et al*., 2018).

Delineation of the catchments and the assigning the overland flow paths represent one of the main steps in the assessment of urban hydrologic modelling. In the sewer shed delineation process the drainage network are an essential component. An accurate analysis of the flow accumulation is necessary in the flow modelling studies.

Major systems in urban zones normally comprise not only roads, sidewalks and natural ground depressions, but also small water channels and ponds (Parece and Campbel, 2014). This system can convey flood over significant distances causing flooding at locations where the drainage capacity is exceeded. Surface runoff from adjacent areas that have no direct connection to the sewer system also contributes to flood flow. Therefore, urban drainage modelling requires a detailed representation of the overland flow network of ponds and pathways to reliably represent surface retention storage, flow paths and volume conveyed. Although surface pathways over urban areas are mainly directed by buildings and streets, water often flows elsewhere through gardens and other open spaces, and this should be as much as possible avoided (Li *et al.*, 2019). Thus, it is important to have a realistic delimitation of terrain and urban structures on the surface when conducting studies to identify the risk zones and in land-use planning management (Thomas, 2014).

Therefore, in flat areas the analysis is more complicated, especially in zones where geomorphic features of concentrated overland are scarce or inexistent.

GIS software contains a hydrologic tool which can be used to derive datasets that describe the drainage characteristics of a catchment basin (Ghebremariam, 2017; Noel, 2014). This module was developed and used to define the various phases of overland flow and its interaction with time dependent water bodies, created as ponds, and the computational inlets to the sewer network. In spatially based distributed analysis, each pixel has an elevation, flow direction and flow accumulation values based on water flow from an upslope to a down slope. The procedure includes DEM preparation, flow direction determination, a flow accumulation calculation, and finally drainage pattern extraction.

The standard procedure in Arc Hydro Tools can delineate the drainage network, also known as the overland flow path, and can be also used for the complexity of water movement in an urban setting. Arc Hydro Tools connects the benefits of water movement modelling to a specific site view of the activity on a hydrographic scale.

The objective of the study is to delineate the regional storm watershed properties in order to perform a drainage analysis on a terrain model. A case study for a small urban watershed illustrates the value of applying this method to delineate the watershed and flow network and forms the basis for hydrological analysis. Additional information, such as the storm drainage network, high-resolution aerial photos, and slopes and aspects of impervious surfaces were to this analysis were included.

2. Data and Methods

2.1. Area of Study

The case study has been made on an urban zone from Kerkrade Town. This hydrographic basin is located in the southernmost province of Nederland, and it forms part of the Parkstad agglomeration. The town covers an area of approximately 22 km^2 of which 0.23 km^2 of water surfaces. The catchment is irregular in shape and the mean elevation is about 155m. The region is mainly a mix of urban, industrial and commercial area whereas the other are the forestry, agriculture and water bodies.

2.2. Data and Methods

The utility of this methodology is used to develop valuable information who are mandatory in the hydrologic modelling. Necessary data used for this are the stormwater network, the water channels and raster data. The entire proposed algorithm for this analysis can be divided into three phases processing of DEMs, flow analysis and basin analysis. A high-resolution base has been used for creating the model.

The sections below describe the concept and modelling processes and outlines the software system developed to perform these tasks. It is emphasized however that the methodology for overland flow modelling can be "coupled" with other physically based urban drainage simulation software packages which use quality GIS for definition of processes on the surface.

Using an elevation raster or digital elevation model (DEM) as input, it is possible to automatically delineate a drainage system and quantify the characteristics of the catchment. The resolution of this raster dataset is approx.

1m. Shuttle Radar Topography is used to obtain digital elevation models (Fig. 1) that generate the most complete high resolution digital topographic database of Earth.

Figure 1 shows the HydroDEM for the study area. HydroDEM has been adjusted using the hydrological tools from GIS software. In the next section, we describe how the HydroDEM was treated in order to represent the influence of urban features on flow direction and flow accumulation stages.

Fig. 1 – Input DEM used and inlets to the sewer network.

The drainage system structures that divert and collect the runoff from the area (Fig. 2) away from its natural way were necessary in order to provide superior results. The location of the drain inlets is represented in the Fig. 1. These will be to use to create sink structures.

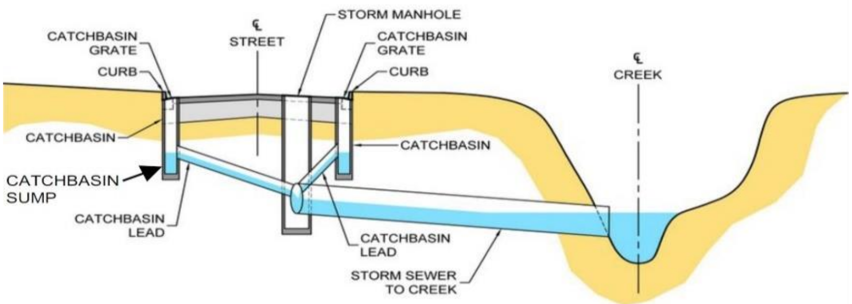

Fig. 2 – Major and minor drainage system in an urban system (Senior *et al.*, 2018).

2.3. Data Processing

This method is simple and straight forward. The spatial analysis hydrology tools from GIS were used to delineate the watershed and flow accumulation network from the LiDAR elevation model. The various processing steps such as fill, flow direction, flow accumulation, watershed delineation, stream order and stream to feature were processed.

Using the DEM as input to the Flow Direction tool, the direction in which water would flow out of each cell is determined.

According to the flow accumulation network, runoff from all the land area within the watershed should flow into the original. So, for the next step of our analysis, we overlaid the storm network shapefile on the watershed, contour lines generated from the LiDAR elevation model, stream channel shapefile, and surface flow network to evaluate how the storm networks would influence or impact water flow within the watershed area. The storm sewer network connects to surface drainage ways and even if they are not part of a natural watershed, they are part of the urban catchment areas.

With the Sink tool, any sinks in the original DEM are identified. A sink is usually an incorrect value lower than the values of its surroundings. The depressions shown in the graphic above (the scattered colored points) are problematic because any water that flows into them cannot flow out. To ensure proper drainage mapping, these depressions can be filled using the Fill tool.

To create a stream network, use the Flow Accumulation tool to calculate the number of upslope cells flowing to a location. The output flow direction raster created in a previous step is used as input.

"Flow direction" is created to compute the direction of flow out of each cell. This tool takes a filled surface as input and outputs a raster showing the direction of flow out of each cell (Fig. 3). These eight integers correspond to the eight possible flow directions (as any given cell is surrounded by eight cells).

Fig. 3 – Flow direction raster.

The delineated watershed is illustrated in Fig. 4. This watershed represents all the area that flows to the specified outlet. The watershed comprises almost the entire area of Kerkrade's town boundaries, indicating that almost all rainfall that lands will go rushing through the actual town, rather than draining away from it.

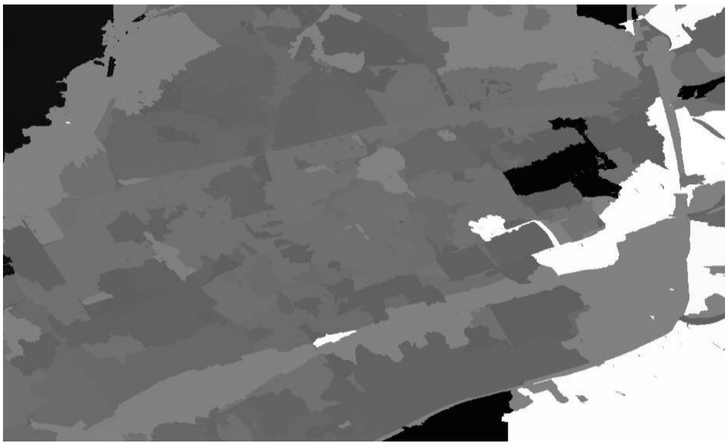

Fig. 4 – Watersheds delineated.

3. Results

The delineation of a particular modeled area affects both terrain complexity and topographical features. These characteristics are related to input data on elevation, soil and land use (Chen *et al*., 2021).

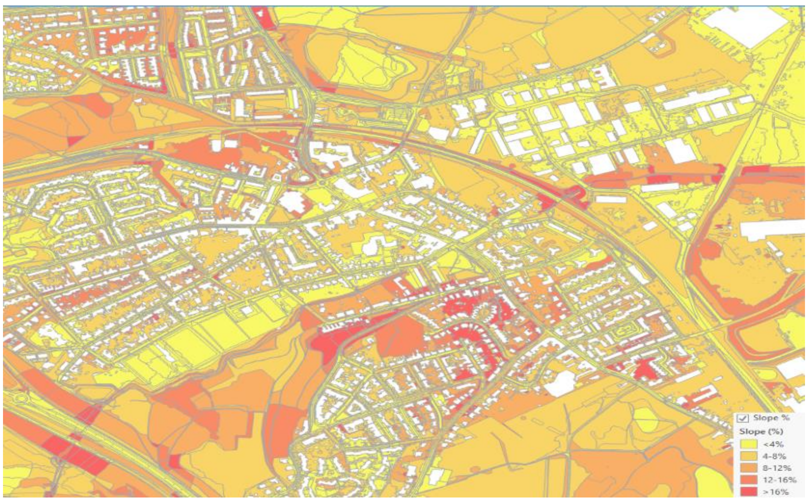

Fig. 5 – Watersheds delineated.

Figure 5 shows results of delineating the watershed from the lidar elevation model. The drainage zones are classified according to the slopes, with slopes values between < 4% and >16%. The zones with yellow are areas with slopes below 4% and represent the flat areas detected in the town, while the ones with red are steeper areas. The watershed is subdivided into lots of sub-basins/ sub-watersheds within each sub-basin. However, the lidar watershed was the most appropriate to use as it appears to include the influence of impervious surfaces in some areas of the watershed delineation.

Our analysis shows the related detailed sewer catchments delineated from which each drain inlet collects the water in an urban catchment. It is apparent that flow is routed in a similar manner and that depressions have been identified. Using this concept, an overland flow path was delineated for the study area (Fig. 6). The results of the catchment delineation are stored in a catchment grid where the values of each cell represent the feature ID it drains to. The catchment grid can be converted to a polygon shape file and linked back to inlets nodes via the pipe ID.

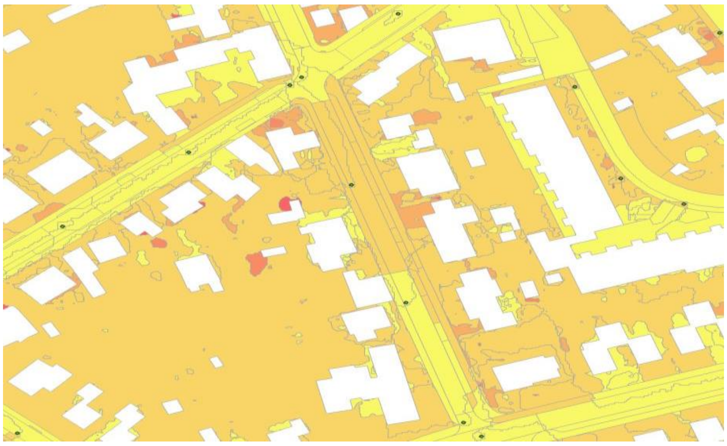

Fig. 6 – Sewersheds delineated related to each inlet.

3. Conclusions

This paper investigated an automated watershed analysis of flat terrains in an urban environment for rainfall runoff modelling. The method is based on the use of the DEM file which supports creation of the surface runoff pathways network. However, it should be noted that full success in implementing this concept depend on the quality of the DEM. Any change in the grid size can causes a corresponding change in estimated value. The method can easily be applied to other urban areas that are equipped with storm water network systems to improve flood risk land use planning and urban flood management. With the storm drain networks, LiDAR and high-resolution aerial photography, GIS can include this data in delineating the watersheds.

REFERENCES

Chen M., Cui Y., Gassman P.W., Srinivasan R., *Effect of Watershed Delineation and Climate Datasets Density on Runoff Predictions for the Upper Mississippi River Basin Using SWAT within HAWQS,* Water, **13**, 422 (2021).

Datta S., Karmakar S., Mezbahuddin S., Hossain M.M., Chaudhary B.S., Hoque M.E., Abdullah Al Mamun M.M., Baul T.K., *The limits of watershed delineation: implications of different DEMs, DEM resolutions, and area threshold values,* Hydrology Research **53** (8): 1047-1062 *(*2022).

Ghebremariam M., *Urban flood modelling: a GIS based approach in Lomma, Skåne region,* Student thesis series INES nr. 439, Lund University (2017).

Karmaker S., Sheikh S., Islam M.S. *et al*., *Watershed delineation in South Bengal Ganges Delta Region of Bangladesh using satellite imagery and digital elevation model*, Arab J Geosci **15**, 997 (2022).

Li L., Yang J., Wu J., *A Method of Watershed Delineation for Flat Terrain Using Sentinel-2A Imagery and DEM: A Case Study of the Taihu Basin*, International Journal of Geo-Information, 8(12), 528, https://www.mdpi.com/2220-9964/8/12/528 (2019).

Noel A., *Watershed Delineation in the Field: A New Approach for Mobile Applications Using LiDAR Elevation Data,* Master of Science Thesis, Purdue University Purdue e-Pubs, Fall (2014).

Parece T.E., Campbel J.B., *Delineating drainage networks in urban areas*, Virginia Polytechnic Institute and State University, ASPRS 2014 Annual Conference Louisville, Kentucky, (2014).

Santiago-Collazo F.L., Bilskie M.V., Hagen S.C., *A comprehensive review of compound inundation models in low-gradient coastal watersheds*, Environ Model Softw 119:166-181 (2019).

Senior M., Scheckenberger R., Bishop B., *Modeling Catchbasins and Inlets in SWMM,* Journal of Water Management Modeling, https://doi.org/10.14796/JWMM.C435 (2018).

Sowmya D.R., Shenoy P.D., Venugopal K.R., *Watershed delineation using SRTM DEM for Bangalore South Region*, International Journal of Engineering Science Invention **9** (3), 01–09, (2020).

Thomas J., *Catchment and overland flow pathway delineation using LiDAR and GIS grid based approach in urban stormwater and sewer network model*, ASPRS 2014 Annual Conference, Louisville, Kentucky, (2014).

DELIMITAREA BAZINELOR HIDROGRAFICE ÎN ZONE URBANE PLANE UTILIZÂND TEHNICI GIS

(Rezumat)

Determinarea exactă a bazinelor hidrografice este încă o provocare în terenurile plate ale zonelor urbane, chiar dacă aceasta este o condiție prealabilă pentru modelarea scurgerii, modelarea hidrologică și modelarea calității apei. Pentru a delimita zonele de drenaj care contribuie dintr-un întreg oraș la scurgerea de suprafață spre gurile individuale de scurgere, care sunt apoi agregate la bazine mai mari dintr-un mediu urban, a fost dezvoltată o procedură de lucru. Scopul acestei lucrări este să identifice proprietățile regionale ale bazinului pluvial pentru a efectua o analiză de drenaj pe un model de teren. Pachetul Arc Hydro a fost utilizat pentru acest studiu, deoarece poate reduce semnificativ procesele care consumă timp, precum și contribuie la îmbunătățirea fiabilității și a rezoluției. Rezultatele acestui studiu arată că delimitarea bazinelor hidrografice urbane din zonele plane poate fi posibilă chiar și în modelele de oraș cu rezoluție mai mică și oferă date superioare dacă se va utiliza o bază de date completă care reflectă realitatea. Mai mult, s-a realizat distincția între bazinele care drenează spre apele de suprafață și cele către rețeaua de canalizare. Rezultatele pot fi uşor utilizate pentru a studia hidraulica sistemelor de canalizare şi pentru planificări viitoare de management.