Impacts of Urbanization on Surface Runoff and Flooding Using Spatial Hydrological Models and GIS

Nazeeh Ibrahim Al Manasyeh*

ABSTRACT

This study aims at applying the GIS methodology to urban growth and hydrological modeling. It presents how to apply GIS in environmental modeling, along with the role of GIS in dealing with hydrological data and extracting information. Impacts of urban growth on surface runoff, and the rainfall–runoff relationship are examined by linking the two modeling results with spatial analysis techniques. This methodology is employed to evaluate the relationship between urban growth and water resources management including flood management into the Lane Cove area, Sydney-Australia.

These applications have been presented through two methodologies. The first is the GIS applications in the theory of surface runoff, and the other is the (SCN-CN) method. Relevant maps are also included. The results demonstrate that highly urbanized areas are more prone to flooding. Urbanization reduces potential maximum storage for soil and thus increases runoff coefficient values.

Keywords: GIS, Hydrological Modeling, Urbanization, Surface Runoff.

INTRODUCTION

The integration of geographic information systems (GIS) has been widely applied and has been recognized as a powerful and effective tool in detecting urban growth (Ehlers and others 1990, Treitz and others 1992, Harris and Ventura 1995, Yeh and Li 1996, 1997). By using the Geographical Information System (GIS) over the study area which is Lane Cove, Australia, this paper investigates whether the surface runoff can be calculated by linking the hydrological models with GIS. It also investigates if it is possible to measure the effect of urbanization on surface runoff. In addition, it assesses the suitability of GIS within an integrated data analysis strategy for the assessment of runoff problems in general.

Increasingly, urbanization, the conversion of other types of land to uses associated with the growth of population and economy, is a significant land-use and land-cover event. The process of urbanization has a considerable hydrological impact in terms of influencing the nature of runoff and other hydrological characteristics, delivering pollutants to rivers, and affecting erosion rates (Goudie 1990). The effect of urbanization on runoff, and related processes, can be assessed against a number of factors especially the size of a flood event. By relating runoff coefficient curve patterns and changes to urban growth patterns in the study area; the effect of urbanization was further revealed.

After developing residential and commercial buildings, increased imperviousness will reduce the time of runoff and build intensity so that peak discharges are higher and occur sooner after the start of a rainfall event in a basin. The volume of runoff and flood damage potential will greatly increase. As a result, the rainfall–runoff process in an urban area tends to be quite different to those experienced in natural conditions such as those depicted in classical hydrological cycles. In any

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event, though, the effect of urbanization will vary according to the size of a flood.

Flooding problems in addition to the fact that Lane Cove area is one of the highest water consumption-per capita in Sydney have drawn the attention of the local council to establish a storm water management system. The Lane Cove River Catchment Management Committee has been established to promote the facility of the water catchment around Lane Cove area in such a way that provides a high quality environment capable of protecting a diverse range of ecosystems in the Lane Cove area. (LCRCMC 1998).

There are approximately 20 overflows annually in the Lane Cove area. These overflows create not only problems for the residents but also affect the ecosystem around the river. The increased amount of the hard surfaces – due to urbanization - in the catchment has lead to a substantial increase in the overflow in the recent years. Modifying the storm water management system would reduce the frequency of the overflow and help preserve ecosystems in the Lane Cove area. The following sections shed light on modeling the runoff in this sensitive area.

This paper attempts to develop an integrated approach to GIS in order to examine the effects of urban growth on surface runoff at the local level. Using Lane Cove as a case study, the specific objectives of this paper are: (1) to detect urban land-cover changes using the GIS and to study spatial patterns of urban growth; (2) to examine the effect of such urban growth on surface runoff; and (3) to evaluate the impact of urban growth on rainfall–runoff relationship.

Methodology

The methodology used in this research is the runoff modeling which aims at converting the precipitation into a stream channel. The other methodologies used are the USDA-SCS and the SCN-CN method. The use of USDA-SCS enables specification of the relationship between the precipitation and the resulting stream. This use of the USDA-SCS methodology depends on critical definitions which are elaborated later in the paper, whereas the role of the SCN-CN is to evaluate the surface runoff from the Lane Cove Catchment area itself.

The integration of GIS is applied to automate the estimation of surface runoff based on the Soil Conservation Service model (SCS). Impacts of urban growth on surface runoff and the rainfall–runoff relationship are examined by linking the two modeling results with spatial analysis techniques. This methodology is applied to the study area. After that an outline is produced. This outline is used for many purposes: first, to categorize the soil types and then the land cover of each type, and second, to assign procedures to recode each map with the CN values for the land cover and soil group.

CN maps are designed by four steps. After a surface runoff image is obtained from the hydrological modeling, the technique of image differencing is applied to evaluate the changes in surface runoff over the time. Then, CN maps are used for the entire area under study. After that, a Boolean map is constructed to portray the steps described above. The urban expansion map is then overlaid with the runoff change map to analyze the impact of land-use and land-cover change on the environment. These methods and implementation procedures are elaborated later in the paper.

The Study Area

The Municipality of Lane Cove is a Local Government Area located about 10km north-west of the central business district of Sydney, Australia, in the south-west corner of the North Shore. The Lane Cove River borders its south, with the eastern part of Hunter's Hill just across that river. It extends westward to Ryde, with Willoughby to the north and North Sydney to the east. The study area is shown in Figure (1).
Figure (1): The study Area.

The Lane Cove River represents one of the most beautiful landscapes in Australia. Its center location and safe environment attract large number of visitors every year. It eventually enters Sydney harbor, itself one of the most magnificent harbor systems in the world.

The Lane Cove sewerage system covers an area of about 52,000 hectares. Land use is a mixture of residential land use – chiefly separate dwellings on large parcels of land – and parkland. Population densities vary from 17 to 30 persons per hectare. The catchment varies in slope between 5 and 10 per cent. Both the storm water and sewerage systems are separate and are dendritic in layout. The major overflow structure is located on a 3.2 m wide by 2.4 m high collector.

The Surface Runoff Theory:

Many studies focus on the issue of urbanization and its effect on surface runoff. Das and Paul (2006), for instance, use the technique of SCS method for estimating the surface runoff for a given rainfall event from small catchments. Other studies look into the relationship between land cover and the hydrological soil group, which together makes up the curve number, are (Schulze et al., 1992, Gangodagamage and Clark, 2001). Curve numbers here vary from 50-100. The higher the curve number is, the higher the proportion of surface runoff (Stuebe and Johnston, 1990; Schulze et al., 1992).

In this study, the runoff modeling tends to convert the precipitation into a stream channel. Many hydrological researchers have focused their attention on obtaining a relation between the precipitation and the resulting stream. Many methods have been proposed to specify this relation. The USDA soil conservation services developed the USDA-SCS method, which has been used all over the world. The USDA-SCS method depends on the following definitions:

- The precipitation (P), which represents the amount of the storm rainfall.
- The retention, which represents the amount of the water that is absorbed on plants or sink in the soil. This amount is called the initial retention (I).
- The amount of the water that would be retained in the watershed while the rain continues (F).
- The maximum amount of the water that could be retained in the watershed (S); The basic proposed
The relation between precipitation and runoff depends primarily on the surface type which is expressed using a dimensionless curve number \( CN \) (\( 0 < CN < 100 \)).\n
CN curve numbers are used to characterize runoff potential from various surfaces. Water bodies are given 100 and for other surfaces \( CN < 100 \). CN curve numbers have been calculated taking into account soil, surface and climate conditions. Through the modeling section of this paper, other aspects and modifications on the USDA-SCS method are discussed, Figure (2).

![SCS CN and Proportional Runoff](image)

**Figure (2):** The relationship between USDA-SCS Curve Number, Precipitation runoff.

**The modeling**

**The Surface Runoff Modeling**

To start modeling, a land cover image and the soil layer were combined and recoded to calibrate CN values with the aid of the standard SCS Table (USDA 1972); and a CN image was thus created. The outline of the work plan is shown in Figure (3).

**Data Collection and Processing**

The introduction of GIS to the field makes it possible for computer systems to handle the spatial nature of hydrological parameters. The hydrological community now increasingly adopts GIS-based distributed modeling approaches (Berry and Sailor 1987, Drayton and others 1992, Mattikalli and others 1996). GIS software has been used to create a file for the twelve data points, each showing easting, northing and rainfall. The rainfall data for the Lane Cove Catchment are given in Table (1). These data have been converted into a vector file using File/ Import/ general conversion tools /XYZIDRIS from the IDRISI menu; and an appropriate reference system has been used. Using the interpolation tools found under GIS analysis/Surface Analysis/Interpolation/ the interpolation process is carried out. Figure (4) shows the interpolation Icon in the IDRISIS software.
Figure (3): Work plan to calculate the runoff in Lane Cove catchment area.

<table>
<thead>
<tr>
<th>Station</th>
<th>Easting</th>
<th>Northing</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cherrybrook</td>
<td>318750</td>
<td>6266487</td>
<td>56</td>
</tr>
<tr>
<td>Pennant hills</td>
<td>321160</td>
<td>6264970</td>
<td>98</td>
</tr>
<tr>
<td>Pearce’s corner</td>
<td>324600</td>
<td>6267300</td>
<td>106</td>
</tr>
<tr>
<td>St. Ives</td>
<td>329850</td>
<td>6266320</td>
<td>48</td>
</tr>
<tr>
<td>Beecroft golf course</td>
<td>319495</td>
<td>6263045</td>
<td>72</td>
</tr>
</tbody>
</table>
Note that the numbers of the rows (640) and columns (600) and the maximum and minimum values for X, Y have been taken from correct dimensions of the Lane Cove Catchment map. These values are available in the metadata. The result of the interpolation process is a map showing the rainfall for every pixel in the Lane Cove area under study. Figure (5) shows the storm rainfall map or the Precipitation Map (P map).

The USDA-SCS and the SCN-CN modeling
The model used for estimating surface runoff in this study was developed by the United States Soil Conservation Service (SCS). It has been widely applied to estimate storm runoff depth for every patch within a watershed based on runoff curve numbers (CN) (USDA 1972).

Now, the task to make CN map for the entire area under study. The first step is to re-divide the soil landscape in the Lane Cove area. The CN values - according to the USDA soil conservation services - have been established based on defining four types of soil; see Table (2).

<table>
<thead>
<tr>
<th>Soil Group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Deep sand, very deep loam, aggregated silts, alluvia</td>
</tr>
<tr>
<td>B</td>
<td>Loam, sandy loam, shallow sands</td>
</tr>
<tr>
<td>C</td>
<td>Clay loam, shallow loams, soils low in organic content and soil high in clay</td>
</tr>
<tr>
<td>D</td>
<td>Soil that swell significantly when wet, heavy plastic clays, skeletal and saline</td>
</tr>
</tbody>
</table>

Table (2): Soil classifications by (USDA 1997).
The second step is to make a map for the study area that converts the soil landscapes in the Lane Cove study area into the four soils types identified by USDA 1997 in Table (2). The result is given Table (3) which shows the soil types assignment that has been done in order to make a map showing the Lane Cove Area with the four soil types and water areas.

Table (3): Soil landscape categories in the Lane Cove study area according to (USDA 1997).

<table>
<thead>
<tr>
<th>Soil landscape in the Lane Cove study area</th>
<th>Soil category according to (USDA 1997)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy loam</td>
<td>B</td>
</tr>
<tr>
<td>Shallow sandy loam</td>
<td>B</td>
</tr>
<tr>
<td>Clay loam</td>
<td>C</td>
</tr>
<tr>
<td>Shallow clay loam</td>
<td>C</td>
</tr>
<tr>
<td>Deep loam</td>
<td>A</td>
</tr>
<tr>
<td>Shallow loam</td>
<td>C</td>
</tr>
<tr>
<td>Alluvia</td>
<td>A</td>
</tr>
<tr>
<td>Man-made fill</td>
<td>D</td>
</tr>
<tr>
<td>Skeletal</td>
<td>D</td>
</tr>
</tbody>
</table>

The third step is to assign the new soil categories to the soil landscape in the Lane Cove study area which is done by using the Assign tool found under Data entry (Figure 6). The final result is presented in a map showing Lane Cove area with four soils types, and water areas (Figure 7).

Figure (6): The Assign tool

Figure (7): Soils types in the Lane Cove study area according to (USDA 1997).
The fourth step is to create a CN map for the study area. The CN map is used to predict the runoff for a given rainfall data (Table 1). It is first intended to assign the appropriate CN value to every pixel in the landscape. There are four ranges of the CN values depending on the soil group to which a pixel belongs. The data provided by (USDA 1997) are utilized (Table 4). Then, CN values in USDA are categorized by land cover and the hydrological soil group. The task here is to assign CN values to each pixel in the Lane Cove study area taking into account the soil type and the land cover over each pixel. Subsequently, a comparison has to be drawn between the actual land covers in the Lane Cove study area and those presented by the USDA (1997) in order to obtain the CN values. Table (4) shows where each land cover in the Lane Cove study area belongs and follows Table (5) for CN values.

<table>
<thead>
<tr>
<th>Land cover in the Lane Cove study area</th>
<th>land cover categories in (USDA 1997)</th>
<th>CN values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thin forest</strong></td>
<td>Forest or woodland: dense stand, deep litter layer</td>
<td>The same value of CN provided by (USDA 1997) for the corresponding category in column 2</td>
</tr>
<tr>
<td><strong>Grassed areas, good condition</strong></td>
<td>Pasture or grassland, lawns, parks, cemeteries, etc: good condition</td>
<td>The same value of CN provided by (USDA 1997) for the corresponding category in column 2</td>
</tr>
<tr>
<td><strong>Grassed areas, fair conditions</strong></td>
<td>Pasture or grassland, lawns, parks, cemeteries, etc: fair condition.</td>
<td>The same value of CN provided by (USDA 1997) for the corresponding category in column 2</td>
</tr>
<tr>
<td><strong>Residential, low density</strong></td>
<td>Residential: low density (approximately 38% impervious )</td>
<td>The same value of CN provided by (USDA 1997) for the corresponding category in column 2</td>
</tr>
<tr>
<td><strong>Residential very low density</strong></td>
<td>Residential: low density (approximately 38% impervious )</td>
<td>The same value of CN provided by (USDA 1997) for the corresponding category in column 2</td>
</tr>
</tbody>
</table>

Table (4): CN values for the land cover the Lane Cove study area derived from (1997 USDA).
Land cover in the Lane Cove study area | land cover categories in (USDA 1997) | CN values | Land cover in the Lane Cove study area | land cover categories in (USDA 1997) | CN values
--- | --- | --- | --- | --- | ---
Commercial, industrial, transport | Commercial, Bare ground, paved, streets | The average values between the commercial, bare ground and streets in the (USDA 1997) | water | Water bodies | The same value of CN provided by (USDA 1997) for the corresponding category in column 2

Table (5): CN values depending on the land cover and Soil categories.

<table>
<thead>
<tr>
<th>Land cover</th>
<th>CN values assigned depending on the land cover and Soil categories</th>
<th>See figure (8A) for the locations of these categories in each soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil categories</td>
<td>A</td>
</tr>
<tr>
<td>Dense forest</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Open forest</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Thin forest</td>
<td>59</td>
<td>69</td>
</tr>
<tr>
<td>Grassed areas, good condition</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Grassed areas, fair conditions</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>Residential, low density</td>
<td>65</td>
<td>75</td>
</tr>
<tr>
<td>Residential very low density</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>Commercial, industrial, transport</td>
<td>87.7</td>
<td>92</td>
</tr>
<tr>
<td>water</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Boolean maps (maps with value of 1 for the area covered by the relevant category and value of 0 for every thing else) have been established to show the area covered by each soil type, and also a map was made to illustrate the water area on the soils map with its correct CN value of 100 and all other areas assigned to 0 (Figure 8A). After that, an image calculator has been employed to multiply each Boolean map by the land cover which gives a map showing the land cover on each soil group. The assign tool has been used to re-code each map into CN maps with CN values appropriate for land cover and soil group based on the CN values in Table (5).
1- A Boolean map for each type of soil based on the map in Figure (7)

2- Multiply each Boolean map by the land cover

3- Re-code the map according to the appropriate CN values for each soil type and land cover

Figure (8A): The procedure to obtain CN maps for each soil type.
The image calculator has been used to add the CN maps for each soil type in order to create a CN map for the entire study area. The image calculator is shown in Figure (8B), and the CN map is shown in Figure (9).

Figure (8B): One of GIS Tools used to calculate the CN map for the study area.

Figure (9): The CN map for the entire study area.

Note: one can see that the water area has a value of 100.
After creating a CN map, the task now is to make an S map that is necessary to proceed from the runoff calculations according to the following relations:

\[ S_{0.05} = 0.818 \times \left( \frac{25400}{CN} - 254 \right) \]

(You-peng and Huai-cheng 2007)

The image calculator was used to obtain the S map. Figure (10) shows the S map for the area under study.

![S Map](image)

**Figure (10): S map for the area under study.**

Now, the task is to calculate the expected runoff by going back to Figure (5) which shows the storm runoff for each pixel in the study area according to the following relation;

\[ R = \frac{(P - 0.05 \times S_{0.05})}{P + 0.95 \times S_{0.05}} \]

(You-peng and Huai-cheng 2007)

Where: R is the run off (mm) and P is the precipitation (mm).

The task focuses on calculating the volume of runoff of each pixel (Q) rather than on calculating the depth of the runoff R. Each pixel in the GIS map represents real area of 25 X 25 m in size. Thus the volume of the runoff is;

\[ Q = \frac{2}{(P - 0.05 \times S_{0.05})} \times \frac{P + 0.95 \times S_{0.05}}{0.625} \]

(You-peng and Huai-cheng 2007)

The total runoff from each subcatchment has also been calculated using the Extract tool found under GIS analysis (Data base Query) in association with the raster image of Lane Cove Catchments. This procedure is used to calculate the runoff from each pixel in the subcatchment represented in the study area. Overlay tool
found under GIS Analysis /Database Query is used to obtain a map showing the surface runoff in the catchments area; see Figure (13). Figure (12) shows the summary statistics from Lane Cove Q map based on Lane Cove catchment map.

<table>
<thead>
<tr>
<th>ID</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Total</th>
<th>Average</th>
<th>Range</th>
<th>Population_SD</th>
<th>Sample_SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>55</td>
<td>2174929</td>
<td>9.49676</td>
<td>55</td>
<td>0.199093</td>
<td>0.199411</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>52</td>
<td>1449601</td>
<td>16.4925</td>
<td>52</td>
<td>0.618578</td>
<td>0.615009</td>
</tr>
</tbody>
</table>

Figure (12): Summary statistics from Lane Cove Q map based on Lane Cove catchment map.
Note: (1 refers to the catchment area and 0 to the areas outside the catchment)

Figure (13): Showing the runoff in Lane Cove catchment area.

Results and Discussion
Urban Growth in Lane Cove
Lane Cove's population was 32,111 inhabitants at the 2006 census. Its density is 3055 persons per square kilometers. In 2006, it was the 66th largest Local Government Area in New South Wales, Australia. It was equal to 0.5% of the NSW population of 6,827,694. At the 30th of June 2006, Lane Cove formed the 89th largest population growth in a Local Government Area in New South Wales (NSW). It was equal to 0.2% of the 58,753 increase in the population of NSW. There was an increase in population over the 10 years to 30 June 2001 of 1,048 people or 3.3% which reached the 85th highest rate of a Local Government Area in NSW.
Hydrological Effects of Urban Growth

Urban growth has many effects. One of these effects is the increase in land use and human activities. Increased urban growth results in an increase in buildings and roads which have less ability for absorbing water, i.e. being impermeable surfaces. As a result, surface runoff is more likely to form streams of water, accelerating runoff to ditches and streams capable of causing floods and further runoff problems. With less storage capacity for water in urban basins and more rapid runoff, urban streams rise more quickly during storms.

The effect of the urbanization on the surface runoff

One can see that the study catchment area is subjected to an increase in the urbanization which leads to a substantial increase in the surface runoff every year. Moreover, the increase in urbanization leads to removing vegetation and soil, grading the land surface, and constructing drainage networks. As a result, floods increase and a change in the stream channels happens which limits their maximum storage to convey flood waters and increase river pollution. To have an insight into the actual situation in the catchment area, one would like to investigate the effect of the urbanization on the runoff. The OVERLAY tool found under GIS analysis tool has been used to obtain a map for the residential, commercial and industrial areas, which have high CN values with regard to the various soil types. The resulting map is shown in Figure (14).

3.3. Impact of Urban growth on rainfall-runoff relationship

Urban growth contributes to a large extent to the intensity of the relationship between the rainfall and runoff. This relationship depends on the change in the potential maximum storage; so, high urbanized areas have less capability of maximum storage and vice versa. Figure (15) shows the relationship between the CN and the rainfall-runoff.

The image calculator is used to obtain a map for the

![Figure (14): (A) The Lane Cove catchment areas with its land covers, (B) The Lane Cove catchment areas with high CN values](image-url)
ratio between the storm rainfall and the runoff in the catchment area, and Figure (15) shows the Runoff/Rainfall map, in addition to the CN map in the catchment.

By showing these two maps together on the IDRISI software screen, one can obtain the result shown in Figure (16).

While in the case of completely urbanization, the relation in Figure (17) is obtained.

Figure (17): shows that the maximum value of the Runoff/Rainfall in the Lane Cove is 50%, and this value reaches 100% in the case of complete urbanization.

Note: This figure gives an idea about how the runoff increases as the percent of the solid surface increases).
6. Conclusion

This paper has shown that GIS can be used to calculate the surface runoff by linking it to the hydrological models, and knowing the effect of urbanization. Moreover, it examines the effect of urban growth on the surface runoff and confirms the common conclusion that urban growth has a major role on the runoff timing and volume in a country by the change in the potential maximum storage. It also causes an increase in land use and human activities; therefore, there will be a decrease in the ability of land to absorb water and causes floods. The runoff in the Lane Cove catchment contributes substantially to the fecal and Nitrogen – Phosphorus pollution. Overflow also compromises safe-swimming conditions and increases the nutrients level in soil causing killing of native bushland. Other problems arise from sedimentation, erosion and declining water and bushland quality (LCRCMC 1997).

The modeling of the runoff by the GIS could assist in developing an effective strategy for the storm water problem and the environmental problems by developing and finding the optimum distribution of the drainage pipes network and developing an integrated sewer and urban drainage systems.

REFERENCES


تأثير التحضر على الجريان السطحي والفيضان باستخدام نماذج هيدرولوجية ونظم المعلومات الجغرافية

تربية إبراهيم المناسية

ملخص

هدف هذه الدراسة هو توضيح كفاءة استخدام نظم المعلومات الجغرافية كطريقة لربط النمو الحضري مع النماذج الهيدرولوجية. إضافة إلى توضيح كيفية عمل نظم المعلومات الجغرافية وتثبيتها على تلك النماذج، ودورها في التعامل مع البيانات واستخلاص المعلومات. بالإضافة إلى تقديم تأثير النمو الحضري في الجريان السطحي، والعلاقة بين الأمطار والجريان السطحي، وذلك من خلال ربط تلك النماذج مع أساليب التحليل المكاني.

تم تطبيق هذه الدراسة على منطقة (Lane Cove) في سدني أستراليا، التي تشهد نمواً حضرياً ملحوظاً في القرنين السابقين، مما أدى إلى تكرار الفيضانات وظهور مشكلات عديدة في إدارة مصادر المياه.

وقد تم تنفيذ هذه الدراسة وفقاً للأساليب؛ يتراوح أولهما تطبيق نظم المعلومات الجغرافية، على نظرية الجريان السطحي وحساب كمية الجريان. في حين يعتمد ثانياً حساب معامل حفظ التربة (SCN-CN)، موضحاً ذلك كله بالخريطة اللازمة والمرفقة بالدراسة.

وقد خلصت الدراسة إلى أن المناطق الححضرية ذات الكثافة العالية في المباني، أكثر عرضة للفيضانات، نظراً لأن النمو الحضري يقلل من كمية التخزين الشبه السطحي، مما يزيد من منافذ الجريان وتكارر الفيضانات.

الكلمات الدالة: نظم المعلومات الجغرافية، النموذج الهيدرولوجي، التحضر، الجريان السطحي.

* قسم الجغرافيا، كلية الآداب، الجامعة الأردنية.

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