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Impact of illegal use of storm network on Tigris River using supervised classification technique

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Abstract. This paper studies the impact of the stormwater network outfall of the Al-Rabee Quarter on the Tigris River. Residents of the district use the storm network for contacts of illegal sewage. Household wastewater is discharged through the storm network directly into the river without treatment, which affects the water quality. Storm network model was developed and use a dynamic wave approach in routing hydraulic flow. The model was simulated based on the calculations of the quantities of domestic wastewater. The supervised classification was used in the spectroscopy of the satellite image of the river by the ArcGIS software in determining the effect of the storm network outfall on the Tigris River. The image was classified into four categories, which are pure water, polluted water, shallow water, and plants. Storm network data was obtained from the Wasit Sewerage Directorate in the form of ArcGIS files. The QuickBird satellite with a high spatial resolution of 25 cm was bought in 2019. The results of the study indicated that sewage quantities were discharged into the river, which led to water pollution by 17.79% from the river surface area. It was concluded from the results that the outfall of the storm network has a high impact on the river water quality. Therefore, this study suggests implementing and managing a separate sewage network that is directed directly to the treatment plants. A stormwater management model (SWMM) was used to simulate a storm network as a sewage network in dry weather.

Keywords: storm network, sewage, image classification, supervised classification, ArcGIS, SWMM

1. Introduction
Sewer drainage systems are one of the most important of underground infrastructure that helps drain stormwater and sewage. Most of the urban areas around the world have a separate stormwater and sewage systems, so there is no risk of combined sewer discharging into rivers. The importance of separate drainage systems lies in maintaining public safety and provide a healthy water environment that does not threaten wildlife and aquatic life. In urban cities, more than 54% of the world's population lives, according to United Nations (UN) reports [1, 2]. So, rapid population growth is increasing pressure on the drainage system [3]. In some cities, sewage from houses is illegally discharged into stormwater networks. In this case, it requires the need to manage and regulate issues of combined drainage systems in all countries. The purpose of this is to treat wastewater before it is released directly into the receiving water and to implement strict laws on the source of pollutants [4].
Remote sensing techniques supports both decision-makers and researchers with the least cost and effort in monitoring spatial changes without the need for field monitoring [5, 6]. Geographic information systems (GIS) is a computer-program and tool for analyzing and mapping events and features on the ground. It integrates common database operations such as query and analysis with maps. This tool is used in governments and companies in the increase the quality of decision-making and problem-solving [7]. Geographic Information Systems, Global Positioning System (GPS), and image classification are significant and powerful analyzing tools in water resources management in obtaining and studying geographical data accurately and quickly [6, 8]. Classifying images is a simple way of visualizing the principal features in a remote sensing image by identifying data values for each pixel on the image [9]. The GIS software can classify the image based on information to a similar group from multiple areas. Classification is a useful and simple tool in measuring and displaying satellite images in ArcGIS software, especially when it is supervised. Image classification is in two ways, which are supervised classification (user-guided), and unsupervised classification (a computer-guided) [9]. Most researchers reported that supervised classification is more accurate than unsupervised classification because it is a combination of personal experience and basic knowledge with the study area [10, 11].

Supervised classification is the technique used in this study. This classification uses training samples (ground truth points) by drawing polygons in the satellite image. The user selects specific signatures that are used to classify the image [9]. Supervised classification is also useful because it used a small number of categories per pixel, allowing for a focused and simplified analysis. The effectiveness of this classification increases if the user is familiar with the study area [10]. The supervised image classification process takes place in three stages: 1) image description phase, 2) the training sample identification phase, and 3) the classification and decision-making phase [12]. Various algorithms are available in this type of classification. These algorithms are minimum distance, support vector machine, maximum likelihood, and parallelepiped. The maximum likelihood algorithm is the most common in supervised classification and most accurate, but it takes time due to its complicated calculation [13]. This algorithm assumes that the cells are distributed in a space with multiple dimensions. It then calculates and assigns pixels to the highest probability class after checking the pixels in each of the categories [12].

Some researchers used spectral classification on the Rivers in their study. Al-Kubaisi et al. (2010) [14] used the data of three satellites are the Landsat7 ETM, Spot5, and QuickBird, with a spatial resolution of 30m, 2.5m, 0.6m, respectively, to spectroscopy of the Tigris River water inside Baghdad using the ERDAS program to determine the pollutants in the river. Their results were that the river’s water can be separated into three, which are natural water, polluted water, and shallow water. Allawai and Ahmed (2019) [15] used ArcGIS software with remote sensing techniques in the spectroscopy of the Tigris river in the city of Mosul, northern Iraq. Landsat 8 satellite images were selected to analyze seasonal differences for four seasons using supervised classification. Their results showed a difference in the values of spectral reflection with different seasons. They reported the possibility of using spectral reflection to distinguish between shallow, clear, and turbid waters.

In Al-Rabee Quarter, the wastewater is illegally discarded from houses into the stormwater network drains. So, the stormwater network works as a sewerage network in dry weather that transports domestic wastewater through the pipelines and into the receiving water (Tigris River) directly without treatment. The research question that this study seeks to answer: Will the drainage of the outfall affect the quality of the river’s water significantly? This research paper focused on locating the impact of storm network outfall on receiving water body represented by the Tigris River using supervised classification by ArcGIS software. As well as simulating a stormwater network as a sewerage network in the dry weather using the stormwater management model (SWMM) developed by the US Environmental Protection Agency’s. SWMM is one of the most significant mathematical, hydrodynamic models which widely tool used by practitioners and researchers in drainage systems and water resources [3, 16, 17].
2. Study area and data

2.1. Study area description

The study area included two cases study: Al-Rabee Quarter and Tigris River. The study area is situated in Al-Rabee Quarter in Al-Kut city. Al-Kut city has lied in Wasit province in the central part of Iraq, 180 kilometers south of the capital Baghdad [18, 19]. Geographically, it is sited between coordinates 45° 50ʹ 00" and 45° 50ʹ 30" E and 32° 29ʹ 30" and 32° 30ʹ 00" N. Figure 1, shows the location of the study area according to the map of Iraq. The total study area is about 21 hectares or 0.21 square kilometers (calculated by ArcGIS software). According to the 2009 census, the population of Al-Rabee Quarter is approximately 4667 inhabitants (Source: Department of Statistic of Wasit), with an annual growth rate of about 3%. The study area has a transitional climate, where it is hot and dry summers and cold and wet winters. Climatic factors play a principal role in environmental changes and the impact of pollutants. The prevailing annual winds in the study area are north and northwest. When it is blowing, it is usually accompanied by dust storms, especially in summer. These winds also can transport pollutants from other areas [20].

The study area contains only a stormwater network that works as a sewage network in dry weather due to the illegal connection of domestic wastewater on it. The number of network pipelines and Manhole numbers are 119 and 119, respectively. The diameters of these network pipes are 315, 400, 500, and 600 mm and made of plastic material. The study area station contains a collection basin and three pumps of the Caprari type.

Figure 1. Location of the Study Area, according to the map of Iraq. Tigris River is the principal source of water [21]. It is home to wildlife, fish, and other aquatic life, in addition to be a resource for industrial, agricultural, and irrigation uses. Many villages and cities extend along its banks. After the eighties, the Tigris River became the focus of many researchers in determining the impact of human activities on the quality of river water [22, 23]. The length of the
Tigris River in Wasit Province is 327 km [22], of the total river length, 1,900 km, approximately [24]. Geographically, the river to be studied is sited between coordinates 45° 50’ 20" and 45° 51’ 00" E and 32° 29’ 40" and 32° 30’ 20" N, as Al-Rabee Quarter stretches along its banks from the west, see figure 2. In the Al-Rabee quarter, sewage is discharged illegally through the stormwater drainage network into this river without treatment. The outfall of the stormwater network for the study area is located under the bridge at the coordinates (X: 4584583, Y: 3249467).

![Figure 2. Location of the study area of the Tigris River.](image)

2.2. Data collection
The stormwater network schematic of the study area was obtained from Wasit Sewerage Directorate. This data was received as shapefiles in the ArcMap within ArcGIS software. The stormwater network schema describes the network characteristics data (Pipes and Manholes). Pipe properties included pipe length, pipe diameter, pipe cross-section shape, pipe construction material, pipe roughness coefficient. Whereas Manhole properties included the invert levels, maximum depth, and offset. Besides, information was collected, and measurements about the collection basin, pump, and network paths, were made through the field visits to the study area.
QuickBird satellite image of the Tigris River in the study area was obtained by purchase it from an external office. QuickBird American satellite image with a high spatial resolution 25 cm, acquisition date 8 February 2019. This satellite image was processed before acquisition.

3. Methodology

3.1. SWMM model description

The Storm Water Management Model (SWMM) has been developed in the early 1970s by three research groups are Metcalf & Eddy, Florida University, and Water Resources Engineers (WRE), and support by the United States-Environmental Protection Agency (US EPA) [25, 26]. Throughout its history diverse, then SWMM has undergone four upgrades, the last of which is the SWMM5 version, and it has been modified to the SWMM 5.1 latest version and manage so far [3, 27, 28]. Moreover, it has an open code and flexible structure. Three methods of hydraulic flow routing are available in an SWMM model, which are steady flow, kinematic wave, and dynamic wave. In this study, a dynamic wave method was used in model simulation.

The drainage network pipeline process assembly is a complex process with unstable flow conditions. The Saint Venant equations are used to describe the unstable flow of drainage network pipelines. They are partial differential equations of the first degree, which consists of the continuity equation (1) and momentum equation (2) [29, 30]. The hydraulic models depend on solutions to Saint Venant equations, which are also called dynamic wave equations. Using the successive approximation method and the finite difference method, SWMM solves the Saint-Venant equation [31].

\[
\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0
\]

(1)

\[
\frac{1}{A} \frac{\partial Q}{\partial t} + \frac{1}{A} \frac{\partial}{\partial x} \left( \frac{Q^2}{A} \right) + g \frac{\partial y}{\partial x} - g(S_0 - S_f) = 0
\]

(2)

Where: \( Q \) is flow rate (m³/s), \( A \) is the cross-sectional flow area (m²), \( x \) is longitudinal distance of channel (m), \( t \) is time (sec), \( g \) is gravitational acceleration (m/s²), \( y \) is water height (m), \( S_0 \) is channel bottom slope (dimensionless), and \( S_f \) is friction slope (dimensionless). The Manning equation can be used in the SWMM model to calculate the steady, uniform flow of the pipe and it is considered one of the best hydraulic equations in open channel flow [32]. The Manning equation is as follows:

\[
Q = \frac{1}{n} A R^{2/3} S_o^{1/2} \quad \text{where } R = A/P
\]

(3)

Where: \( Q \) is volumetric flow rate (m³/s), \( n \) is manning roughness coefficient (s/m⁴/₃), \( A \) is the cross-sectional area of conduit (m²), \( S_o \) is the channel bottom slope or slope of the hydraulic grade line (dimensionless), \( R \) is hydraulic radius of conduits (m), and \( P \) is the wetted perimeter (m).

3.2. Storm network model representation

The storm network was represented in figure 3, which consists of 119 Junctions, 119 Conduits, a Storage unit, 3 Pumps, and Outfall, which was drawn by the toolbar in the SWMM model. All physical parameters obtained from the network schema were determined. The quantities of sewage have been entered into the network nodes (junctions), which it is calculating explain later.
3.3. Dry weather calculations (sewage quantity calculations)

In the Al-Rabee quarter, household wastewater is illegally disposed into the stormwater network. Therefore, the stormwater system works as a combined system in dry weather. Calculations of wastewater flow are mainly based on population density and daily per capita water consumption. Sewage flow (wastewater flow) was calculated by the below equations.

In this study, the population number is determined by the growth factor method. The rate of increase in population growth is 3%. The population in the future was calculated from the equation below [33]:

\[ P_n = P_0 (1 + i)^n \]  

Where: \( P_n \) is the future population, \( P_0 \) is the current population, \( i \) is the annual growth rate, \( n \) is the number of years.

The quantity of water consumption locally is 400 liters per day according to Wasit Sewerage Directorate. 20% is deducted from the quantity of water consumed, which is used for garden irrigation. The discharge of average consumption calculates from the following equation [34]:

\[ Q_{av.} = 0.8 \times q \times P \]  

where: \( Q \) is the discharge of average consumption (m^3/s), \( q \) is the quantity of water consumption (m^3/s), \( P \) is Population number. The maximum peak factor was calculated from the following equation [35]:

\[ P \cdot F = \frac{q}{\sqrt{P}} \]  

where, \( P < 80,000 \)
where: $P.F$ is a coefficient of a maximum peak factor, $P$ is Population in thousand. The maximum flow of sewage calculates from the equation below [33]:

$$Q_{max} = Q_{av} \times P.F$$

(7)

where: $Q_{max}$ is the maximum flow of sewage ($m^3/s$). Maximum infiltration flow may be calculated from the equation:

$$Q_{inf.} = 0.1 \times Q_{av}.$$  

(8)

where: $Q_{inf.}$ is the infiltration flow ($m^3/s$). The infiltration factor depends on the condition of the drainage network and is calculated in the case of surface/groundwater infiltration into wastewater.

Design wastewater quantity was calculated as equation follows:

$$Q_{des.} = Q_{inf.} + Q_{max}.$$  

(9)

where: $Q_{des.}$ is the design drainage quantity ($m^3/s$).

3.4. Satellite image classification

Several authors declared that the supervised classification technique is the best for spectral classification using remote sensing techniques [36]. As, the maximum likelihood algorithm in supervised classification is considered the best large-scale technique in satellite image data analysis, which has a high accuracy in classification. This algorithm uses a second-order Gaussian probability distribution function (PDF) [13].

$$f(X) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

(10)

where: $\sigma$ is the standard deviation, and $\mu$ is the mean value.

In this study, a supervised spectral classification technique using ArcGIS software was applied to determine the water types of the studied portion from the Tigris River. The steps of the spectral classification process are as follows [10, 15, 37]: 1) The processed QuickBird satellite image was used in this study. This QuickBird image with a high spatial resolution that does not need any improvement because of the colors of the river are clear within the spatial resolution for image 25 cm. This satellite image is suitable for the classification process in ArcGIS software. 2) Depending on the visual discrimination, the change in the colors of the specified river was very clearly observed. As, the colors of polluted water were observed depending on the difference in the values of gray levels, especially the water areas surrounding the outfall of the drainage networks. This is given a good impression to perform the classification process on this image data. 3) Using the Polygon tool in the GIS software, the categories were determined by zooming in and out of the image to obtain the river’s features. Twenty-four random training samples were selected for the river according to the change of watercolors, based on the visual interpretation of the satellite image. Four classes were identified, one class for each group of samples. The river was classified into four categories, which are natural waters in a dark blue color, water polluted in red, shallow water in light green, and a plant in dark green color, see figure 4. After completing all operations, the satellite image was classifying.
4. Results and discussion
The research results include simulating the storm network in the Al-Rabee Quarter as a sewage network as well as the supervised classification of the satellite Image of Tigris River into which the storm network is discharged into it.

4.1. Network simulation in dry weather
A simulate of the stormwater network was performed in dry weather as a sanitation system. The sewage water that leaves the Al-Rabee quarter houses illegally was entered in the SWMM model because the Al-Rabee quarter contain only a stormwater network. Figure 5 present a profile plots showing the sewage flow in 5 main paths. These paths show the quantities of illegal household sewage in the stormwater network pipelines, which are discharged directly into the river without treatment.

4.2. Satellite Image Classification
The supervised maximum likelihood classification technique was used in the spectral classification of the river in the study area through the QuickBird satellite image data. The river was classified into four classes, which are pure water, polluted water, shallow water or sediments, and plants, as shown in figure 6.

![Image](image_url)

**Figure 4.** Training sample manager.
Figure 5. Sewage profiles plots for 5 main paths.
Figure 6. The river after the supervised spectral classification process.

As shown in figure 6 Pure waters represented a dark blue color, the polluted water red, shallow water or sediments in light green, and plants in a dark green. A large increase in the red color of the water under the bridge is observed, and it continues with a length of 750 meters, and later begins to gradually decrease. This color indicates the presence of polluted water as a result of the drainage of the outfalls of the storm networks (which work as a combined system) into the river. A close-up image for spectroscopy of a satellite image of the river, as shown in figure 7, showing the outfall of the stormwater network for the Al-Rabee and Al-Sharqiah districts. The overall classification accuracy result of the satellite image was 95%.
Figure 7. A segment of the spectral classification illustrating the outfall location of stormwater system Al-Rabee Quarter.

The percentages and areas of water classes are shown in table 1. The pixels of the satellite image have also been recorded in table 2. It shows from the two tables that the percentage of the polluted surface area of the river’s surface was 17.79%, here it is necessary to refer to the need for the subtractive water to be treated before it is released into the river. Also, to be noted not to allow to erect water intakes for any purpose in the areas shown as in figure 8.

| Water class    | Area (Km²) | Area (%) |
|----------------|------------|----------|
| Pure Water     | 0.577      | 55.56    |
| Polluted Water | 0.186      | 17.97    |
| Shallow Area   | 0.23       | 22.11    |
| Plants         | 0.047      | 4.36     |

Table 1. Area and percentage of water classes using the supervised classification.

| Water class    | Pixels    | % Pixels |
|----------------|-----------|----------|
| Pure Water     | 1660162   | 55.17    |
| Polluted Water | 537081    | 17.86    |
| Shallow Area   | 674838    | 22.42    |
| Plants         | 136994    | 4.55     |

Table 2. Pixels count and percentage of Pixels using the supervised classification.
5. Conclusions and recommendations

This paper included simulating the stormwater network using the SWMM model during dry weather because it is working as a combined system. The study main goal was to locate the impact of network outfall on the receiving water body represented by the Tigris River. The following are the conclusions extracted from this research with the represent of suggestions:

- The results of the supervised classification for this QuickBird satellite image showed the possibility of distinguishing polluted water by sewage pollution sources about remaining water because the organic content for sewage reduces the reflectivity of the water, which makes it easier to distinguish it visually through the satellite image.
- The results indicated that the outfall of the stormwater drainage network that operates as a combined network due to the illegal connection of wastewater has a significant impact on the water quality in the river. Therefore, the authors suggest taking the necessary measures in managing the drainage of this network and implementing a separate sanitation network that would be directed directly to treatment plants.

Authors recommended to future researchers using other satellites with high spatial accuracy to identify polluted water in other drainage networks outfall.

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