SIMULATION OF RIVERS WATER FLOW BASED ON DIGITAL ELEVATION MODEL CONSTRUCTION

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ABSTRACT

(DEMs) are the technologies that represent the topographic of the earth's surface accurately, especially if they are based on accurate surveying data. These models can be used to construct three-dimensional surfaces through longitudinal & cross sections, slopes, and elevations which can be derived from field observations.

This research aims to build DEM or 3-Dimensional surface for studying the reality of rivers. The study area will be different rivers that branch out from Shatt Al-Arab in Basra/Iraq. The first stage based on filed surveying or data acquisition. This will be adopted to construct a one dimensional unsteady numerical flow model that simulates the state of hydrodynamic flow and water flow within the river, in order to predict its current behavior according to the highest and lowest tides using the HEC-RAS software.

The simulation results will identify the areas of weakness that cause defect, affect or impede the flow of water within the river stream. Afterwards, the simulation results will be used to redesign the river stream with levels, slopes, longitudinal and cross sections (Construction new design model). This will be achieved according to design standards which can restore the natural flow of the river without interrupting the water cycle in any part of river, and with elevations that corresponds to the highest and lowest tides level. Through this model, these rivers system achieved their levels, flows and velocity required for water to ensure full water replacement and renewal within 24 hours (in all tidal periods throughout the year), thus ensuring the restoration of these rivers and the prosperity of life and treatment of pollution, to become a clean environment can contribute to the prosperity of the economic and tourism aspect in the city of Basra.

Key words: DEM, Simulation Model, HEC-RAS, Rivers of Basra.

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1. INTRODUCTION

Rivers are systems of complex behavior that are difficult to predict in terms of their behavior and water characteristics such as levels and flows. [3] Therefore, simulations are used to predict their levels and conditions according to user defined time periods and according to real survey data of river shape and water levels. [2]

The simulation models of rivers are the techniques by which the behavior of rivers and water characteristics can be investigated in a clear manner. These models can provide us the characteristics of water within rivers such as velocity, flow and levels. It also gives accurate results about the geometric characteristics of the shape of rivers, such as longitudinal and cross sections, their specifications and areas of strength and weakness. [1] Simulation models need to define the characteristics of the study area in a precise manner to give accurate results, in particular the definition of the geometric characteristics of the rivers of study area, which were represented in this study by the main rivers branch of the Shatt al-Arab in the city of Basra. [2]

In this study, the main rivers branching from the Shatt al-Arab in the city of Basra will be dealt with as a study area for simulation purposes and predicting their behavior. The main rivers of Basra currently consist of six main rivers. Each of these rivers is connected at the end by a vertical link made up of three groups connected to each other in a contract form (Siraji-Khoura groups, Ashar-Khandak groups, Ribat-Jhaila groups). The main purpose of link is to rotate the water between the Shatt al-Arab and the channels to clean the water inside the rivers. Water is fed to these groups from the Shatt al-Arab, the flow of water entering and exiting into the three groups is influenced by the phenomena of tides. [4] Recently, these rivers have been exposed to pollution and turn into outlets to get rid of the rotten water, so this research will try to build a simulated model for these rivers in order to address the most important problems and return them to their previous status before pollution. [5]

2. STUDY AREA

The study area consists of rivers group of Ribat-Jubaila. The length of Rabat River is 4320 m while the length of Jubaila River 3825 m and the length of the river link between them 1740 m [6]. Al-Jubaila Rivers is previously dug for the discharge of groundwater, and stems near the silo of Basra. The steam of river is blocked and the pollution is very high. It is characterized by the stone-paved banks, and currently runs as a narrow water channel that spread near its upstream empties area. Currently that is used to accommodate the slums, the rest of the land uses adjacent to it are residential and commercial. Al-Ribat River is attributed to the Governor of Basra (Ribat Malik bin Dinar), who ordered the digging of this river in this place. This river penetrates a large district and divides it into two parts: the Large Ribat and the Small Rebate, surrounded by the residential land uses of both sides [3]. Water is fed to the rivers system from Shatt al-Arab. The flow of water entering and exiting into the two group of Ribat - Jubaila is influenced by the phenomena of tides. Recently these rivers have turned into shallow marshes where stagnant water and waste collected at bridges and culverts that penetrate rivers, as well as low-level areas of the river. This has resulted in the reduction of the impact of the phenomenon of tides which in turn has caused the pollution to increase and settle in the bottom levels as the waters no longer reach the ends of the rives. [5]

In this paper, four corrected satellite images for the year 2015 were used to produce the paths of these rivers and their banks from both sides. Each satellite image corrected using the GIS program based on 8 ground control points for each image, the ground control points were obtained from the (Czech company BOCP) which contracted with the Municipality of Baghdad to update the master plan for the city of Basra, where this company has observed
accurate coordinates by GPS to georeference the satellite images. The satellite images of (60 cm) resolution have been corrected in GIS depending on GPS points and Georeferencing tool, where the RMSE of all satellite images is not exceed than 60 cm after the georeferencing, as in the Figure (1), figure (2) and table (1), which illustrates one sample of the steps of georeferencing the satellite images using the georeference tool. Based on the corrected satellite images, all six main rivers of Basrah city were plotted with their links and all their side branches using the GIS program. The figures from Figure (3) to Figure (6) can illustrate the plotting and calculations steps in the program.

These rivers, drawn by (ArcMap-GIS), will represent the boundaries of the study area within the (HEC-RAS) program.

Figure 1 The georeferencing for the satellite image of the city of Basra by ArcMap. Georeferencing tool by GPS coordinates
Table 1 Link table of Georeferencing tool which illustrate coordinates of GPS points that used in correction of the satellite image with its RMSE

![Image of Table 1](image1)

**Figure 2** Mosaic all satellites image of the city of Basra
Source: The researcher based on the ground control points and the GIS program.

![Image of Figure 2](image2)

**Figure 3** Steps of plotting river paths in the GIS program using the editor tool

![Image of Figure 3](image3)
Simulation of Rivers Water Flow Based on Digital Elevation Model Construction

**Figure 4** All rivers paths of Basra city after plotting in the GIS program by editor tool

**Figure 5** The reality of the six major rivers of the city of Basra after adding grid and legend

**Figure 6** the steps of using the GIS attribute table to calculate the lengths of main rivers of Basrah city

Source: The researcher based on the satellite image for year 2015, and the (GIS) program.
3. HEC-RAS SOFTWARE

The HEC-RAS software was produced by the United States Army Corps of Engineers in 1996 and continued to evolve to the latest version of the program (HEC-RAS 5.0.3) in 2017. This software provides an advanced state of the other software that deals with water flows, due to the graphical interface which permits, the users to see the input and the local errors before starting the simulation. Moreover, HEC-RAS does not need any additional software to display the results because it implicitly has all the software to display the results as drawings or tables. [7] In this research the HEC-RAS program will be used to construct a one dimensional hydrodynamic numerical model to simulate the hydrodynamic flow in the Basrah Rivers for unstable flow state. This model is based on the solution of continuity and momentum equation in the longitudinal direction of the river using the difference finite method. [8]

The data required to run the program include two sets, each set must insert successively geometric data, and initial and boundary conditions. [9] The Geometric data include the river sit plane and the manning coefficient values. River shape data include cross-sectional shape data along each river and the distance between them (each length) to construct a digital elevation model for these rivers. [7] Initial and boundary conditions: initial condition is the solution of unsteady flow equations requires the determination of the values of all variables (water levels and flow at upstream) at zero time, known as the initial conditions. [10] Boundary condition is the values of the temporal change of levels or flows. The maximum flow occurs in the Shatt al-Arab in month of May and the lowest in the month of November. So the hydrodynamic flow in Basra Rivers will be simulated during the months of May and November. Tidal elevations will be adopted in these two months to determine the boundary conditions required to operate the model. [11]

4. STAGES OF MODEL CONSTRUCTION

The research will rely on simulation as a methodology in building DEM that simulates the reality of the rivers and obtain results that explain the reasons for the transformation of the Shatt al-Arab rivers into stagnant swamps and sporadic channels that are not influenced by the tide phenomenon. The same tool will also be used in designing a new DEM that addresses the
research problem and achieves its goals. The Scheme (1) can illustrate the requirements needed by the simulation program to simulate the rivers and obtain accurate simulation analysis.

4.1. Building the digital elevation model for the rivers of the study area

The research will be determined by group of rivers (Ribat-Jubaila) as a study area. The constructing of digital elevation model of the group of river in the study area is in that will base on add surveying data. The survey data divided the rivers into a number of cross sections along the length of the river, at a distance of no more than 100 meters (between section and another), and then using GPS device to observe at least 6 points within each cross section (center and sides of the cross section). This was done to illustrate the topography of the earth and change in the shapes of sections with high accuracy. The cross-sectional coordinates have been relied upon to build the digital elevation model in (Civil 3D Land Desktop 2015) software, where the central line of each river was drawn, and hence defined as a path (alignment) for longitudinal and cross sections. After that, a three-dimensional surface was constructed and modified by Interpolation for surveying points confined between the sections, then, modify the Triangulation Irregular Network (TIN) to increase the accuracy of the cross section representation, as shown in the Figure (7) and figure (10). After the construction of the three-dimensional surface it will be exported to the HEC-RAS as (DEM- Digital Elevation Model) format and as (GIS Format) extension, which is considered as input to the HEC-RAS.

Figure 7 constructing the 3-dimensional surface of the Ribat-Jbaila Group

Figure 8 Surface before modification
4.2. Inputs of HEC-RAS

4.2.1. Geometric data

These data represent the digital elevation model that was built for the rivers of the study area, which determines the shape of the river stream and defines the longitudinal and cross sections to the simulation program along each river, as well as the distance between each cross section.

After importing these data into the program, the coordinates system have been set as (UTM-WGS1984-Zone 38N), and then, the direction of the flow and the definition of the riverbed and their banks were determined. The program thus gives two and three dimensional shapes showing the locations of the cross sections, their characteristics, shapes and digital models. [7] This can be seen in the following Figures
Simulation of Rivers Water Flow Based on Digital Elevation Model Construction

Figure 11 The shape of the river stream of the Ribat-Jbaila group

Figure 12 The longitudinal section of the Ribat-Jbaila Group, which shows the change in level of riverbed and river banks
4.2.2. Manning Coefficient

To compute the value of the Manning coefficient, the Manning equation was applied within each cross section. Equation variables were computed by using the (Civil 3D Land Desktop) program and based on the cross sectional data for calculating the area of cross section $A_j$, the hydraulic radius of $R_j$, the slope between the section and another. The flows $Q_j$ are calculated in each section in March and November based on the initial values of the Manning coefficient. [12] Manning coefficient values were obtained and ranged between $(2.1 \times 10^{-5} – 3.09)$ for the Ribat-Jbaila Group. These values change due to the roughness of the surface and increase in areas with low levels in which the waste accumulates, and the shape of their cross section and their riverbed level are irregular, causing waste deposition, increasing the roughness of the riverbed, obstructing water flow and reducing its velocity. These values were introduced for the simulation program. [13] As shown in Figure (15)
Figure 15 The introduction of the Manning coefficient for the rivers of the study area in March and November

Source: Researcher depending on (HEC-RAS 5.0.3) program

4.2.3. Boundary Condition
For the purpose of operating the simulation model, the research will depend on the tidal levels as inputs to the boundary condition in March and November, where the highest tide and lowest ebb occur in these months. These levels change every 6 hours a day and throughout the month due to the semi-daily tidal cycle occurring in the Shatt al-Arab.

In March the level of tide reaches as high as possible (at 3:00 pm on the 26th of the month to reach 1.893 above mean sea level), and in November the level of ebb reaches as low as possible (at 1:00 pm on the 21st of Month to reach -0.707 above mean sea level). [11]

4.2.4. Initial Condition
The flow and velocity of the upstream of each river at zero time was calculated based on the boundary conditions data (average tidal levels in March and November), as well as the
geometric data of the river shape. The slope was based on the average slope of the water surface at the tide in the Shatt Al-Arab (2.075 * 10^-6) to represent backward water curve.

The flows of all tidal levels were also calculated in March and November at the upstream, taking into consideration the average slope of water surface of the Shatt al-Arab at the tides (the average slope of Shatt al-Arab water surface at the upstream of the rivers is 1.15 * 10^-6 during the tide period and towards the top of the river, while in the period of ebb 3.01 * 10^-6 towards the bottom of the river). [10]

4.3. Outputs of HEC-RAS for the reality of rivers
After defining all the inputs to the HEC-RAS 5.0.3 program, a numerical model was constructed that simulates the reality of the Ribat-Jbaila group and operation it. After the operation, the program produced results that could determine the characteristics of river and its main problems.

The results of the model can be seen in the following figures. These figures simulate the temporal change for the higher level of the tide in the month of March and lower level of the ebb in the month of November through the longitudinal and cross sections to show random change in the levels of riverbed and level of tides in each cross section along river stream. Furthermore, they highlight the cross sections and stations where water cycle is interrupted and tide wave don’t reach to it along each river of group. In addition, tables and diagrams were produced to represent the values of flows, velocity and levels within each section. The relationship of each of those values to each other is also depicted.

When these figures are observed, there is a rise of the riverbed levels from the tidal levels in some parts of the river, especially in the sections with irregular side slopes where the upper width of the section increases, and the riverbed levels change with the change of stations and sections with irregular slopes reaching the highest level near the bridges and arches, there are no apparent longitudinal slope in a particular direction. We also notice the interruption of the water cycle in most of the sections adjacent to the residential buildings, shops, random housing and slums because of their waste and pollutants that are being dumped in the river directly causing an increase in the level of bottom of the river.

As the theoretical framework of the research proved that the group (Ribat - Jbaila) is one of the most concentrated rivers around the slums and increase in the density of residential and low availability of green area adjacent to the rivers, and proved that these rivers have the largest area of coverage of solid waste offered by the land uses adjacent to these rivers, it is expected that with such conditions the wastes will accumulate at any obstruction that interferes with their flow such as pedestrian bridges that penetrate these rivers and are based on the iron pillars, as well as narrow culverts of the car bridges that penetrate the rivers also, causing loss of energy tide and the lack of access water to the end of the river despite the height of elevation in the Shatt al-Arab. Therefore, there is a need to redesign the streams of the rivers and their cross-sections and slopes in such a way as to ensure that the water cycle does not breakdown in any month of the year, especially in the months of March and November, and allows for a daily renewal of this water in each group. It is also necessary to increase the healthy green areas of land and open areas adjacent to the rivers and reduce the proportion of Residential buildings, excesses and squatter. After running the model, results are also produced with reports representing water velocity and flows that change with distance in each cross section.

The following image show the Changes of water surface level in the longitudinal section of the Ribat-Jbaila group for the highest level of tide in March and November.
Simulation of Rivers Water Flow Based on Digital Elevation Model Construction

**Figure 16** Change of water surface levels in the longitudinal section of the Ribat-Jbaila group for the lowest level of tide in November and March

**Figure 17** The locations of stations where the water cycle is interrupted in Ribat-Jbaila group for the highest & lowest level of tide in March & November.

**Figure 18** the locations of stations where the water cycle is interrupted in Ribat-Jbaila group for the highest & lowest level of tide in March & November

Source: Researcher depending on (HEC-RAS 5.0.3)
4.4. Outputs of HEC-RAS after applying the design proposals on the rivers' sections

For the purpose of ensuring the continuity of flow and the complete replacement of water in the rivers of Basra, some changes were proposed in their longitudinal and cross sections, and then the model is operated according to these changes, as follows:

1. **Shape of the river's cross-section:** When the model is applied to the reality of the river, the difference between the level of tidal waves decreases as we move from the upstream towards the back of the river (Link area between rivers), which results in a decrease in flow and velocity to affect the mixing process and replacement of water. Therefore, the study suggested reducing the flow area as the distance from Shatt al-Arab increased, which means the design of cross sections that narrow the upper width whenever we move away from the upstream, to maintain high values of the flow velocity. In accordance with the (continuity equation), in which the flow velocity is inversely proportional to the area of the cross section in case the water flow is stable.

   Therefore, the study suggested that the shape of the cross section at the upstream of each group of rivers in a trapezoidal shape, to allow the entry of the largest amount of tidal water from the Shatt al-Arab, then change the shape of the section into a rectangular section with a vertical wall when moving away from the Shatt al-Arab, to increase the velocity and discharge of water, as in Figure (20).

2. **The cross section's levels and their depths and upper width:** In order to ensure continuity of runoff in the rivers and the absence of interruptions in the water cycle in any part of the river, and to ensure the increase in the volume of water replaced in each tide cycle, the research proposes to reduce the levels of reverbed and increase the depth of the cross sections in proportion to the highest level of tide (which occurs in March with value of 1.89 m), and the lowest level of the ebb (which occurs in November with value of -0.71 m to mean sea level), so that it is not less than the level that provides continuous flow, not exceeding the level of the banks or the level that causes an undesirable increase in the stable storage of water within each river group.

   To ensure that rivers are used for river transport by riverboats used in Basra, the depth of the river should be greater than the depth of the submersible part of the boat. According to the river transport standards that correspond to the Basra Rivers, the depth of the water under the submersible of the boat shall be at least (0.3 m), and the depth of the boat's submersible shall not exceed (0.8 m).

   As for the width of the watercourse, the river boats should be allowed to move in two directions. If the width of the riverboats does not exceed (2.45 m), the width of the river should not be less than (8 m), as follows:

   - \((2.45 \times 2 + \text{distance of 1m between two boats} + \text{distance of 1 from banks of rivers})\)

   Therefore, the research suggests that the level of the river bed should be at least (1.81 m) under mean sea level, and according to the (UTM-WGS84-Zone 38N) coordinate system, as follows:

   - The lowest level of the ebb (-0.71) + Submersible part of the boat (-0.8) + (-0.3) under boat diver = -1.81

   The depth of the cross sections in the two river groups shall not be less than (4.2 m) according to the following:
Simulation of Rivers Water Flow Based on Digital Elevation Model Construction

- The difference between high and low tide level (1.89+0.71) + depth of the diver (0.8+0.3) + 0.5 between maximum level of tide and river bank= 4.2 As in Figure (19).

3. **The lining of the cross sections**: The research suggests lining the river's stream and their sections with concrete walls and beds, because the concrete has low coefficient of roughness, and works to increase the velocity of water and its flows, prevents leakage of water to the soil, and reduces the salinity phenomenon that occurs at the banks.

4. **The longitudinal slope of the riverbed**: The research suggests that the slope that connects the bottom of the rivers is equal to zero, that is, the riverbed of all the rivers in a horizontal way, because the horizontal slope is used in the design of the river bed affected by the phenomenon of tides to prevent water stagnation at the ends, allows the water to be replaced faster when the tide occurs, the horizontal slope also helps to maintain a constant depth of the boat's submersible part not less than (0.8 m) when the waters of the ebb reach the lowest level.

5. **Design proposals for river's stream**: to ensure that no infringement or impact on any land use adjacent to the banks of rivers, and to ensure the exploitation of the resulting areas of narrowing the width of the river's section in the establishment of tourism and recreational activities, and also ensure the increase characteristics of flow, and non-interruption of the water cycle and faster replacement of water, and to achieve the conditions and standards mentioned above, the research proposed dividing the groups of river into four work areas in each group. Each work areas has a certain length and starts with the starting station at the upstream of the river, and increases along the river up to the end station at the downstream. Each work areas was given a certain code with certain design specifications based on the simulation results to meet the conditions mentioned above. As for the shapes of the proposed cross sections for each work area, they can be illustrated in Figure (20), where the shape and width of the cross section changes in each work area to achieve the above suggestions and standards. These values and dimensions were fixed after being tested with the simulation model. Based on the design proposals, the new digital elevation model of the rivers group, which links the proposed cross sections, was constructed as in Figure (21). (HEC-RAS 5.0.3) will rely on this digital elevation model to simulate water movement and flows and predict future behavior.

![Figure 19 Width of the river stream that proportional width the river boats](image)
Figure 20 Specification of proposed cross sections for each work area
Source: Researcher based on (HEC-RAS 5.0.3) outputs and (Civil 3D 2015).

Figure 21 The new digital elevation model of Ribat-Jbaila constructed based on the proposed cross sections
Source: Researcher based on (HEC-RAS 5.0.3) outputs

After running the model according to the design proposals proposed by the research as geometric data, and relying on the tide data as initial and boundary conditions, the model gave results. These figures illustrate the results of simulations in March and November to show the increase in the flow energy and the flow velocity which resulted in the regularity of the water surface levels and the disappearance of the areas where the water cycle is interrupted in all parts of the river. Thus, the research proposals have achieved its purpose in addressing the river’s stream and rehabilitating them if these proposals are adopted in design and if the
program (HEC-RAS) is adopted for the simulation purposes because of its accuracy in the results, predictions and dealing with survey data.

**Figure 22** Regularity of water level in longitudinal section of the Ribat-Jbaila group for the highest level of tide in March after applying design proposals

**Figure 23** Regularity of water surface levels in longitudinal section of the Ribat-Jbaila group for the lowest level of tide in November after applying design proposals

**Figure 24** Regularity of all water levels at all tides intervals for the month of March for the Ribat-Jbaila group
Figure 25 Regularity of all water levels at all tides intervals for the month of November for the Ribat-Jbaila group

Figure 26 Longitudinal distribution of flow velocity values along the Ribat-Jbaila group for the highest level of tide in March after applying design proposals

Figure 27 Longitudinal distribution of flow velocity values along the Ribat-Jbaila group for the lowest level of tide in November after applying design
5. CONCLUSIONS
There are several findings and outcomes that outlined from the investigation and analysis of this research, which can summarized as follow:

1. The RMSE resulting from georeferencing the satellite images of the study area did not exceed the resolution of the satellite image (60 cm), where the RMSE in the first image was (0.389), while the second image was (0.595). The RMSE for third and fourth image were (0.411), and (0.368) respectively.

3. The Manning roughness coefficient increased due to the irregularity of the cross sectional forms and the riverbed roughness. For the study area, it was reaching (3.84). After the re-design the cross sections according to the research proposals, the coefficient of Manning reaching to (0.025). This indicates the decrease in the value of this coefficient based on the regularity of the cross sections.

4. The difference between the levels value of rivers observed by the researcher at highest and lowest periods of tide, and the elevation obtained from the Iraqi Ports Department for the same periods, did not exceed 1 cm. This indicates the accuracy of the initial and boundary conditions used for the purpose of simulation.

5. The results of the simulation demonstrated by the application of the numerical model to simulate the reality of the main rivers of Basra indicate that there is no ease in the flow of tidal water due to the accumulation of pollutants and wastes of various kinds at the riverbed of these rivers, to contribute of raising the level of the riverbed, and prevent the water of Shatt al-Arab from the arrival to the ends of these rivers.

6. The accuracy of the simulation results depends on the accuracy of the geometric data and the initial & boundary conditions. Therefore field surveying data with accurate survey instruments, in particular (Differential GPS). Should be used to show the real change in velocity, flows and level values in all parts of the river. Thus accurate river reality simulation, and the accurate prediction of its future behavior.

7. Through testing the simulation inputs, it has been shown that reducing the width of the cross sections at the banks whenever moving away from the river upstream can contribute to increasing the velocity and flow of water, and can also increase the area of the spaces at the banks and provide places for tourism and recreational purposes.

9. It is not possible to use mathematical equations and diagrams to represent the temporal change of water levels within the cross sections of rivers, or to be used to represent changes in
hydrodynamic properties of water, because they change randomly and continuously with time. Therefore, simulation is the best way to represent this change and predict its behavior.

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