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Article

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Modelling Data of an Urban Drainage Design Using a Geographic Information System (GIS) Database

Abstract

This paper describes the development of a model to interface a planned urban drainage system with Geographic Information System (GIS) through the introduction of open-source tools; *Auto Numbering* and *Get Elevation* to extract essential data from GIS and *Excel2GIS* to bridge the output data between GIS and the drainage design program. Creating a range of essential data from digital database repositories aids the development of decision-support tools for urban planners in a simulation of different urban drainage scheme scenarios and moderates the interference with other infrastructure utilities. These tools, modelled with design software and GIS platform, are tested in two case studies; the results revealing essential improvements in accuracy of output, time taken to prepare and run the model and model presentation which visualised the hydraulic design results and global location of the drainage layout on an urban master plan.

Keywords: Extracting data using GIS repositories, modelling design data, open-source tools, producing profile, urban drainage system.

1. Introduction

The rapid development of complicated master plans for cities and infrastructure utilities has resulted in drainage systems which are also complex, including substantial amounts of data for design, analysis, operation and management (Yazdanfar and Sharma, 2015). Urban drainage system design traditionally requires substantial data in order to produce tables and maps which illustrate the system and avoid intersecting with other infrastructure utilities (Ferreira and Duarte, 2006). However, urban planners struggle to deal with all the documents required to manage the system and its data because system elements are interrelated and the planners need to be aware of the relationships between them and how they impact on the whole system (Jin and Mukherjee, 2010). The implementation of a variety of scenarios for the designed drainage system requires sophisticated procedures and intense data from many infrastructure authorities in the city in order to achieve optimisation and resilience (Mikovits et al., 2017); therefore, developing and adopting decision-support tools improves the design, management and operational performance of the infrastructure urban planning (Kizito et al., 2009). Urban drainage system functionality depends on building topological links and the interactions between this system's elements and other utilities' elements (White and Stewart, 2015). In order to achieve feasible points for optimal design and operation, it is important to define all the roles of the elements throughout the system (Jurišić et al., 2014) and select an optimisation model which impacts on the results of the control system (Mollerup et al., 2016). The task of providing combined management for infrastructure utilities is gaining more awareness and the principles of Integrated Urban Water Management (IUWM) have become important considerations for both city planners and researchers (Bach et al., 2014).

The basic goal in drainage system design is to determine the optimum layout and the proper size of the conduit (pipe or open channel) required to carry the flow, and to provide a smooth gradient that keeps the hydraulic integrity requirements within the limitations of the hydraulic design criteria(Mays, 2001). Size-wise, the drainage system is bigger when compared with the other infrastructure utilities such as electricity lines, potable water networks, gas pipelines, etc.; therefore, the areas occupied by this system and which have the potential to conflict with other utilities are considerable. Many planners combine green infrastructure and traditional drainage systems to design facilities for stormwater drainage; this method decreases peak flow, allowing the use of smaller sewer pipes (Johnson and Sample, 2017; Kong et al., 2017; Liu et al., 2017). However, although this scenario decreases the size of sewer lines, the area used by the drainage system is still big. Achieving a feasible design with the best possible layout is challenging due to the difficulties involved in balancing these criteria (Duque et al., 2016).

An awareness of the city's master plan, including the existence of other infrastructure services such as electricity and communications lines, potable water networks, gas pipelines and ground gradient, is key for the optimisation of the urban drainage system layout and allowing for an ideal and feasible drainage system planning (Li and Matthew, 1990). Computer models and mapping software such as GIS have been very helpful in assisting planners and authorities to find practical solutions to the interference between different infrastructure utilities. They enable them to build a vital relationship between elements (Sanzana et al., 2017) and improve the urban drainage system performance by mitigating flash flood events (Liu et al., 2017; Zhang and Pan, 2014). Due to the complexity of environmental models such as urban drainage systems, traditional system designs which extracted data from block map input tables are no longer used (Morsy et al., 2017). Using GIS as a Computer Mapping Program (CMP) provides efficient and accurate tools for urban drainage systems as it links and exchanges data with other field layers such as meteorology, censuses, the city master plan, hydrology and geology, enabling urban authorities to save the time and costs usually associated with a conventional approach to infrastructure services (Mustajoki and Marttunen, 2017). The value of using GIS comes from the fact that more than 80% of water and wastewater infrastructure data has already been geographically referenced. For example, 90% of infrastructure authorities in the US use GIS applications in utilities management (Shamsi, 2005); a similar proportion has been found in the UK and other parts of the EU.

Interface methods, development tools to interface with GIS, have been used to assess and improve the management and planning of drainage networks (Halfawy et al., 2007) and to enhance applications such as the optimal placement of model elements or system controllers

(Leitão et al., 2018; Nielsen et al., 2017; Riaño-Briceño et al., 2016; van Daal-Rombouts et al., 2016). Many commercial packages, which have started to upgrade to communicate drainage modelling with GIS, in their recent versions, are trying to utilise a GIS database to improve the drainage system layout. Commercial drainage design products, such as Bentley SewerGEMS and XP-PSWMM, provide the ability to interface with GIS. Much of the input data is created automatically; for example, pipe length is calculated from the pipes' coordinates. This enables the user to test several layouts before settling on the optimal design. The user can also easily depict and label design drawings (Katti et al., 2015). Others, for example, PCSWMM GIS, use an integration method with GIS, building a software design package inside the GIS interface, using the same programming language as GIS; this avoids the need to exchange data between GIS and drainage design programs (Sinske and Zietsman, 2002). However, the majority free version trial of these are not appropriate for educational and research purposes as they limit the number of conduits that can be included in the designs, whilst others are simply not accessible for development purposes (Riaño-Briceño et al., 2016).

Commercial packages using CMPs such as CAD and GIS are thriving as this technology provides for up to date and accurate integration of data from other layers of a city's master plan – such as length of pipe, impervious coefficient of the area, and ground elevation of the nodes. However, there are still challenges for the designer in integrating this data between a hydrodynamic drainage model and urban development GIS database, extracting the input data such as an appropriate sequence ID for the network system elements, or the ground elevation, coordinating the system for the drainage system elements, and accurately determining the area served by the drainage system elements. Many researchers model urban drainage input data using GIS according to the taxonomy described by Shamsi (2005), which comprises Interchange (Loose coupling), Interface (Tight coupling) and Integration (Seamless coupling) methods (Bhatt et al., 2014; Liu et al., 2014; Pontes et al., 2017; Qin et al., 2017; Wang et al., 2016).

This paper presents new three tools (*Auto Numbering*, *Get Elevation* and *Excel2GIS*) to model essential design drainage input data using a GIS database which can improve the planning performance by running many scenarios for the drainage system design and visualise the interference with other infrastructure utilities; Excel is used as a link between the design model and GIS. This saves significant time and costs compared with the application of traditional methods and some commercial models and improves the level of accuracy.

2. Methodology

2.1. Software architecture

The tools presented in this research are suitable for researchers and planners to use with their models or available as open-source drainage system design models and easily integrated with GIS databases to extract input data. These tools are open-source repositories, licensed and published under the GNU General Public License v3.0 https://github.com/Ghassankhaleel/Get_Elevations, https://github.com/Ghassankhaleel/Auto-Numbering and https://github.com/Ghassankhaleel/GIS_2_Excel). The tools require Windows 8 or later, Microsoft Office and GIS or Open Source GIS (QGIS).

The structure of the model implementing these tools, illustrated in Fig. 1, describes the principles used to build the tools in the model. The first part from the structure (Extract Input Data) is applied to extract data from the GIS repository database for use as input data to design an urban drainage system; sketching the layout in GIS is the first step in this structure. The program design is the second part of the model. It includes two subroutines, one for sewage flow design and the other for storm drainage design. Users can use an alternative open-source urban drainage design program but they need to manage the input data table extracted by these tools in an Excel format, amended to match the format required by the model. The tools, *Auto Numbering* and *Get Elevation*, are active at the space between the GIS repository and the design model. The *Excel2GIS* tool gathers the extracted data and creates Excel file input data which can then be used as input by the urban drainage design program. In the third part of the model (Simulate Output Data), the same tool, *Excel2GIS*, will receive the output data from the design program Calculation Report and convert the data to shape files which can be used to visualise the results through the GIS repository database. The visualising of results in GIS allows planners to figure out the interference of the drainage system with other layers of utilities and analyse more than one planning scenario before deciding on the final one. The user can use the GIS database to produce different versions of maps for the drainage system output showing the interface with other city features.

Fig. 1. Flowcharts showing the structure of the embedded tools in the model for extracting input data of an urban drainage system's design.

2.2 Auto Numbering: building the topology of drainage systems using GIS

The geometric network that GIS provides is a vital facility by which to build an urban drainage system network, defining the topology i.e., the relationships – between elements of the system. For example, it can link a conduit to a node. The majority of conduits starts or ends with nodes such as manholes in a sewer system, although a small number of pipes does end with an outfall or at a pump station (PS) or treatment plant (TP) in the network. A geometric network enables the user to edit network elements such as the pipe or open channel (line), automatically creating nodes (manholes). This process can be performed inversely by editing the manhole, automatically linking it with the pipe (Grise et al., 2001). This process saves the designer or user valuable time, allowing amendments to the network, which will behave as a correlating system. If the user moves the manhole from one point to another location on the map, the pipe will automatically move with it. If the network is built through a geometric process, GIS provides active tools for the network analyst, enabling a visualisation of the behaviour of the drainage system and the ability to test it, for example, changing the direction of flow or adding barriers that can change the flow route. This topological relationship can be used effectively within commercial software to analyse and test a multitude of scenarios regarding flood management (Totman, 2017; XP Solutions, 2015). This topology between network elements accelerates the editing process for the network layout in the master plan using GIS. There are two potential ways to identify the horizontal alignment of drainage networks; the first is to identify the pipe, the second one is to identify the manhole and use it as a reference to give an ID for the corresponding pipe that connects two manholes (Butler and Davis, 2011). Identifying the elements in the network is one example of initial input data that can be used when designing a model. Researchers have used the advantages provided by geometric networks to build a model of the relationships between network elements, as it allows them to create a unique reference number (ID) for each. The form of ID can be proposed by the user, and is usually a number sequence for the main line (trunk line) which is nominated by the user; this is used as a reference to number the other elements in the network. This starts from the end of the network (outfall, PS or TP), by marking it as the zero point, allocating ascending numbers for the nodes (manholes) upstream of the main line. The tool numbers the elements (manholes) automatically, giving priority to branches on the right and then on the left side, using the trunk line which was manually numbered by the user as a reference. The tool depends on calculating the slope (the angle between links) as the method to identify the next manhole. In order to set the next manhole number, taking the next ascending number after manhole ( ), the software looks for the slope for each intersection point with , where as shows in the equations (1-1, 1-2 and 1-3)

$S1$ of ——) (1-1)

$S2$ of —— (1-2)

$S3$ of —— (1-3)

(*x* and *y* are the coordinates for each intersection (node)). When determining the values of S1, S2 and S3, the software numbers each manhole sequence in a counter-clockwise rotation. Fig. 2(a) shows the sketch for the numbering processes for the innovative software used for numbering the system and which has been successfully applied in two case studies.

Fig. 2(b) shows the sketch for the numbering processes in the interface of the Auto Numbering software tool.

Fig. 2. The innovative software used for numbering the system **(a)** sketch of manhole numbering process in the tool and **(b)** interface of the *Auto Numbering* software tool.

2.3 Get Elevations and Extract Data from GIS: using Differential Global Position Systems (DGPS)

One important feature of GIS is its ability to extract the properties of the drainage system from other features that are available in the database such as street routes and gradient of the area (Haile, 2009). Commercial drainage design modelling uses this facility to automatically extract the ground elevations for nodes (manholes) from Digital Elevation Models (DEMs) of the design area. However, the accuracy of the output elevations depends on the DEM data which are susceptible to raster image resolution (Arnone et al., 2016; Li and Wong, 2010). The DEMs do not have the accuracy required for use in sewer system modelling design and are generally only applicable to natural landscape modelling (ASCE, 1999, cited in Shamsi, 2005). Selecting a suitable survey method is one of the most challenging decisions that a designer (Rayburg et al., 2009) or authority in charge of a drainage system has to make, bearing in mind the suitability of the chosen technique and the disadvantages and advantages of the selected method. Today, DGPS is not just a faster method; it is also the most accurate method available, providing density of data collection (Young, 2012). In this study, the DGPS method was more flexible in enabling the creation of a digital table of elevations at one-metre intervals with a given coordinate system for each point. This digital table was imported by GIS and created an elevation grid layer covering all streets and the extension area in the case study. Fig. 1 (Supplementary material) shows the interface and process of the *Get Elevation* tool. The tool inputs elevations for nodes, established by selecting the closest point of elevation to the node from the GIS survey layer created from DGPS, which is the second set of input data that GIS provides. Fig. 3 shows that it is possible for the user to determine the diameter of a circle (the 'range circle') within which the node should search, to keep the accuracy within acceptable limits by find the closest elevation level. In this case, 2.5 metres was used as the diameter for the range circle around the node; the program found two elevation points available within this circle and assigned the level from the closer one (the point that was 1.15 metres away from the node). Each manhole has an elevation, but if the elevations for some manholes cannot be obtained these can be fed in manually.

Fig. 3. The process of matching the manhole with a nearby topographic elevation.

2.4 Excel2GIS tool: extracting input data from GIS layers

The use of GIS has initiated a new era of easy communication between features on the ground and the ability to link different layers of city master plans. GIS can help the designer to extract all the necessary input data, the iterative data (Dile et al., 2016), and prepare it for use in the drainage design program (Kong et al., 2017). Data extracted by this method is more accurate in comparison to using a manual data feed as the process avoids human error and can save much of the time and effort required to manually link areas to the corresponding pipes required by some commercial sewer design software. The *Excel2GIS* is a feedback data tool in two ways, extracting data from GIS database to hydrodynamic model as input Excel file and exporting the output data from hydrodynamic model to GIS database as shape files. The efficiency of using this tool with the associated *Auto Numbering* and *Get Elevation* is that to improve the performance by depicting the layout of the proposed drainage system by GIS, which gives the planner the ability to assess and evaluate more than one alignment path, allowing identification of the optimum one at the first stage, as shown in Fig. 1. This process offers advantages with reference to time and effort as it is a straightforward task to delineate the drainage system, visualise the results and identify any conflict with other layers and infrastructure. It is still necessary to collect data from local authorities or conduct a site visit for specific locations to identify any interference with other infrastructure services, but the amount of work is reduced, as stated by Jankowfsky et al. (2013). Greene et al. (1999) attempted to computerise the selection of the appropriate layout for drainage systems by choosing some criteria and integrating them with GIS feature layers. This allowed the identification of the optimum path for the drainage system connection sequence and detection of a suitable location to site the lift station. However, in spite of this, GIS cannot replace the judgement of professional designers, based on their experience, which enables them to avoid barriers and select the best routes (Luettinger and Clark, 2005). After setting-up the route for the network and determining the location of the nodes (coordinating the system for each element, which is then used as a function to integrate the drainage elements (layers) with other layers in GIS Geodatabase), it is a straightforward task to create the initial data. This begins with the identification of networks by allocating a unique ID to each node in the system. This system identification allows the results of the design data to be linked with elements of the network. These IDs can later be used as a reference when linking historical data available for future maintenance or planned inspections (Rettig et al., 2014). Ground elevations for each node and the length of link (pipe) between pairs of nodes will be determined by the *Get Elevation* tool; this process provides the design program with the initial data to create the optimum incline for each link. This guarantees the required self-cleaning velocity of the flow through the pipe or the channel and helps to estimate the lining cost. While determining what area, linked with each element, contributes to the estimated flow in each link, Fig. 4 shows the process of linking pipes/areas in close vicinity to each other. The benchmarks to determine the zone of sub-catchment area drains to each link are the two nodes connected to the link (Jang et al., 2018; Xie et al., 2017). GIS database layers are used to determine catchment area properties that intersect with drainage system elements. The repository data for these layers was assigned as attributes and can be used to extract the required data, such as impervious factor or land use, and assign it to the sub-catchment element area layer overlaid with it (Chang et al., 2015; Roy and Shuster, 2009).

Fig. 4. Process of linking the area of property (A) with the pipe.

Table 1 shows the initial data that can be extracted automatically from GIS as an Excel input file using these tools for drainage design programs. This data represents the initial data for the drainage design program such as catchment area of each link, the length measurement of each link, node numbers (ID) in sequence, ground level at node locations, and the coordinates system of the two nodes (Manhole No. 1 and Manhole No. 2) that are connected at each link.

Table 1

Input file extracted from GIS.

2.5 Drainage system

The development of a hydrologic and hydraulic computer model provides an effective means of evaluating the hydraulic capacity of a drainage system under dry and wet weather flows (Vallabhaneni et al., 2007) and improves the management storage capacity process of the drainage system (Cunha et al., 2016). To date, several hydrological and hydrodynamic models have been exploited and developed, such as the Bentley SewerGEMS, XP-PSWMM, Infoworks CS, and MOUSE, as a commercial modelling package, and SWMM, as an open-source model developed by the United States Environmental Protection Agency (EPA), and can be used to simulate the water flow of drainage systems and provide a fully hydrodynamic pipe flow model (Liu et al., 2017). In this case study, a specific drainage design program approved by the municipality authority was used. A circular pipe shape and Prandtl-Colebrooks formulas were employed in the concept of this hydrodynamic model for the pipe design; the flow conditions are predicted more precisely by the Colebrook-White formula (Valiantzas, 2005), based on the exact flow equation 2 by Darcy-Weisbach:

(2)

H_f: friction head loss in m, λ: friction factor, L: unit length, D: diameter in m, V: velocity in m/s, g: acceleration due to gravity.

In order to determine the friction factor (λ), Colebrook-White introduced the following formula (Equation 3) based on the theory of boundary layers by von Karman and Prandtl (Chadwick et al., 2013):

(3)

: roughness coefficient and *Re*: Reynolds number.

The formula published by the Hydraulics Research Station (Equation 4) was used to determine the flow velocity (Chadwick et al., 2013).

(4)

S_f: slope of the hydraulic gradient, υ: kinematics viscosity in m^2/s

By estimating the discharge for each pipe in the drainage network using Equation 5 and Equation 6, the corresponding pipe diameter required is calculated.

(5)

A: catchment Area feeding the pipe, *PD:* population density, *DC:* Discharge per capita and *inf*: Infiltration

(6)

The diameter can be determined from the q_{actual} peak while the slope can be set as the minimum slope at the beginning. Hydraulic properties such as flow velocity and flow depth can be found by iterative calculation as the discharge, diameter, and slope of the pipe are known. The program used was for a two-part, separate sewer system, one part to design the sewage flow system, the other to design the storm flow system. These tools can also be used for the design programs of combined sewer systems because both normally require the same initial input data.

3. A case study application to validate the tools with an urban drainage model

Two areas in the Middle East (Iraq) were selected to apply these tools in association with a study conducted by Al Ghalowa Co. Ltd. to plan the optimum scenario to design the drainage system for these cities, which have faced a growing number of flash floods in the last decade within the current boundaries of their built-up areas. The drainage system plans take into consideration the future extension of the cities' built-up areas until 2040. Table 2 shows the features of the two sites and Fig. 2 (a) and (b) (Supplementary material) illustrates the two cities' land use. Currently, the two cities use the onsite sewage facility (septic tank system) to drain the sewage flow, which is vacuumed by the water authority vacuum tracks regularly. The two cities have a few pipe systems and open channels for the drainage system and to discharge the stormwater flow outside the built-up area; however, the capacity of the existing system is now not enough to carry the flow during heavy rain events. This prompted the water authority to develop a drainage system plan for each city to last until 2040. Therefore, the design plan for the drainage system has been scheduled to be constructed in two stages. The first stage covers the current built-up area and the second stage will serve the future extension of both cities. Fig. 5 (a) and (b) demonstrates the current built-up area, future extension boundary and existing drainage system of Afak city and Al Hamza city, respectively. The challenge that the authorities and planners face is that each city has complex infrastructure services such as electricity networks, potable water, and communications system.

Table 2

The features of the two case study sites (two cities in Iraq).

Fig. 5. (a) The boundary of the built-up area and future expansion area for Afak city (**b)** The boundary of the built-up area and future expansion area for Al Hamza city.

These infrastructure services mean that constructing a new drainage system has a high potential risk of increasing the cost of the project without the adoption of a rigorous design plan to avoid and manage any conflict with these existing infrastructures. Fig. 3 (a) and (b) (Supplementary material) shows the electrical networks in Afak and Al Hamza cities and how they intersect with the routes of the proposed drainage system. The tools presented in this research enable the planners to run more than one scenario for the new drainage system which can manage the intersecting between the alignment of the drainage system and other infrastructure routes; this is implemented at the first stage illustrated in Fig. 1. When the second process of the drainage system design was run and the size of the system elements was determined, it checked again if the system was intersected by other utilities. This occurred in the third stage shown in Fig. 1. This process was repeated before the optimum design was decided.

4. Running the model and simulating output data

The second data input stage required for the design, as shown in Figure 1 at the design programming stage, is performed by the program interface itself. This constitutes the data for the whole drainage system and includes population density, discharge per person, pipe material, minimum velocity, and minimum and maximum cover depth. It represents the general input data used to estimate the discharge from each area and the hydraulic properties of the system. This allows optimisation of the design process as more than one scenario can be tested by changing the parameters applicable to the data and analysing consequent effects (Mair et al., 2012). This offers more resilience by allowing the user to evaluate the effects of variations in design parameters. Fig. 6 (a) shows the interface of the drainage design program (Sewage), the initial input data extracted by tools, embedding the second set of data, in order to complete the input data form required for the design program. The difference between the sewage design and storm design sections is the general input data required by the design program interface. The storm interface program requires concentration time (minutes), the return period of the storm frequency (years), and the impervious factor of the area (runoff of coefficient); this information allows the model to calculate the storm runoff. The roughness of the pipe, minimum and maximum cover depth, and storage capacity for the storm network can be defined by the user. Fig. 6 (b) shows the interface of the drainage design program (storm design).

Fig. 6. Sewer design program interface used to input general sewer network data **(a)** sewage system and (**b)** stormwater system.

4.1 Visualise the results geographically

The results are produced as a calculation report in an Excel file. Table 3 shows a sample of an Excel results file; all elements having a coordinate produced by GIS are linked with the output from the hydraulic model. The interface between GIS and hydraulics output allows the geographical simulation of the design results (Elliott et al., 2016), improving the construction performance by avoiding any conflict with sewer routes, managing barriers and decreasing project times. *Excel2GIS* has been used to transfer the results to the visual stage by producing a vector mode from the results file (Dile et al., 2016). This can then be used to create a GIS Geodatabase of the sewer design program output and produce many different map versions. It can also be integrated with other layers in the GIS repository and by sharing data with other environmental models (Morsy et al., 2017). These resultant vectors can be simulated, via profile drawings for the sewer network, to create a link between the design results, simulated in a visualisation. This reflects the shape of the sewer elements and material of the pipe, such as PVC pipe or GRP pipe, or the pump station building, and includes the location of each element in the sewer network. This process makes it easier to know locations in the district and within a whole city because of the integration with the city map layer in Geodatabase and the automatic linking of each profile sheet with District Name, Sheet No. and Network No., as shown in Fig. 7. This profile has several advantages over other profile styles, for example, showing the level and diameter of the pipes that intersect with the pipeline profile. This means it is straightforward for the contractor to recognise the location of a pipe within the network and city, making the construction stage easier and faster when compared to the traditional style of profile drawings.

Table 3
Sample of calculation results data file.

Fig.7. Sample of profile map that visualises the network elements.

4.2 Choice of an appropriate scenario

Three scenarios for Al Hamza city and two for Afak city have been selected for this research using the initial construction cost of laying pipe networks as a criterion of comparison, Table 4. Fig. 8 (a) shows the comparison of the initial construction cost of the wastewater networks of Al Hamza for three scenarios, which shows high variation in the cost. The same high level of variation is shown for the three scenarios for Al Hamza’s storm drainage system illustrated in Fig. 8 (b). These scenarios studied different layouts of the wastewater networks trying to avoid intersecting with other infrastructure utilities, and included the area from the second stage (future extension) in the first stage. The research considered the use of the open channels available in the city as a drainage system to drain stormwater, keep it as an aesthetic feature for the city in scenario 1, and convert it to a pipe system in scenarios 2 and 3. The research did not discuss the details regarding scenarios and policies of authority or planners in selecting the optimum scenario, as they are outside the scope of this research. The scope is to present the facilities provided by the tools that integrate the hydrodynamic model with GIS in order to accelerate and improve the planning performance. The two scenarios of Afak city, Fig. 9 (a) and (b), were not complicated compared with the scenarios of Al Hamza city due to the simplicity of Afak's master plan and the size of the city. Similar principles regarding the scenarios were applied to validate the cost when extending scenario 1 to scenario 2 to cover the larger future extension area and were also applied in stage one of the project. It was the same for the storm drainage system, as the designer tested the cost when using the existing open channels in the proposed drainage system (scenario 1), and when converting these open channels to a pipe system in scenario 2. The construction cost is increased under scenario 2. Selecting the optimum scenario is a complicated process involving population, economic and social behaviour (Mikovits et al., 2017). Therefore, in this case study, the authorities selected scenario 2 to avoid the garbage collecting in the open channels during dry seasons and to decrease the risk of flash floods, because these open channels can become clogged in the rainy season if not cleaned regularly.

Table 4
Cost of lining the pipes for each scenario of Al Hamza city and Afak city.

Fig. 8. A comparison of three Al Hamza scenarios using the initial cost of construction as a criterion **(a)** for the sewage drainage and **(b)** for stormwater drainage.

Fig. 9. A comparison of two Afak scenarios using the initial cost of construction as a criterion **(a)** for the sewage drainage system and **(b)** for stormwater drainage system.

Fig. 10 (a) and (b) demonstrates the elected scenario (scenario 2) designed by tools and simulated in the GIS platform to produce a variety of maps for both cities. These maps can comprise other layouts and details of utilities such as electricity cables or potable water pipes available in the GIS repository and provide details of any interference with the new drainage system through construction stages; this enables the water authorities to avoid too much conflict with other infrastructure authorities and landowners.

Fig. 10. The optimum scenario of the drainage system design (sewage) of produced by the support tools, which includes the network details for the current built-up area and trunk lines for the proposed future area **(a)** for Afak city and **(b)** for Al Hamza city.

5. Conclusion

Programming software tools using GIS repository data to produce the input parameters for environmental models such as drainage system design have attracted the attention of many researchers recently because of the richness of the data held by GIS. The current research has presented three software tools that use the GIS repository to create the initial input data for sewer system design: *Auto Numbering*, *Get Elevation* and *Excel2GIS*. These tools use Excel and can play a critical role as the interface media between a drainage design program and GIS, improving the performance of the drainage design programs. Such programs can stand independently and not be affected by any GIS updates that occur as these tools generate data in the form of Excel files which constitute the links for both the drainage design program and GIS. Employing topology facilities to build geometric networks between elements of the sewer network through GIS offers very powerful advantages regarding the delineation of drainage networks, at the same time providing a valuable and reliable process. Integration between other layers available in the GIS repository and sewer networks makes it possible to extract initial input data such as the area served by a pipe, length of each pipe and sequential numbering of network elements as well as matching of ground elevation with manhole location, produced as an Excel file for use as input data for the sewer design program. This saves time and effort, avoiding the tedious process of transferring data manually; its flexibility offering the opportunity to test more than one scenario when designing a drainage system.

The ‘Generate vectors feature’ (shapefiles) from the hydrodynamic design program output is an Excel file, produced using *Excel2GIS*, which is a software tool that can export and import the results of a design program to GIS and connect this data with the attributes of each feature such as a pipe or manhole. This allows for the visualisation of the sewer design elements, their location on the map, and a simulation of the flow direction and pipe material while also including the hydraulic properties of the design in the GIS database. The profile produced using this tool shows the intersections of pipes that connect with the profile of the pipe laterally. It includes scaling of the dimensions of the pipe diameters and levels of the pipes in profile. This facility is novel to this research and is not available in any other commercial design sewer system package. Its advantage lies in the ease with which the sewer network can be monitored at the construction stage. A profile map can be created linking the pipeline with its location on a small-scale map and a city map, as well as producing different styles of data maps via GIS.

The program has been tested successfully via two case studies (Afak city and Al Hamza city) in cooperation with Al Ghalowa Co. Ltd. in Iraq, the results reflecting the accuracy and flexibility of integrating sewer design programs with GIS using Excel as an interface media. It was possible to run more than one scenario for the drainage system design to manage interference of the drainage system with other existing utilities in these cities before deciding on the optimum design, including the storm drainage network and sewage drainage network. Using the tools presented in this research provided planners with flexibility and a high level of accuracy as human error was avoided in transferring input data; it also saved time and sped up the testing of more than one design of the drainage system, and provided the ability for the hydrodynamic design program and GIS to communicate to produce a variety of maps for the drainage system.

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Declaration of interests: The authors declare that there are no potential conflicts of interest associated with this research.

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Availability of data and materials: Raw data were generated at Liverpool John Moores University. The derived data supporting the findings of this study are available from the corresponding author (A. Abbas) on request.

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Figure 1

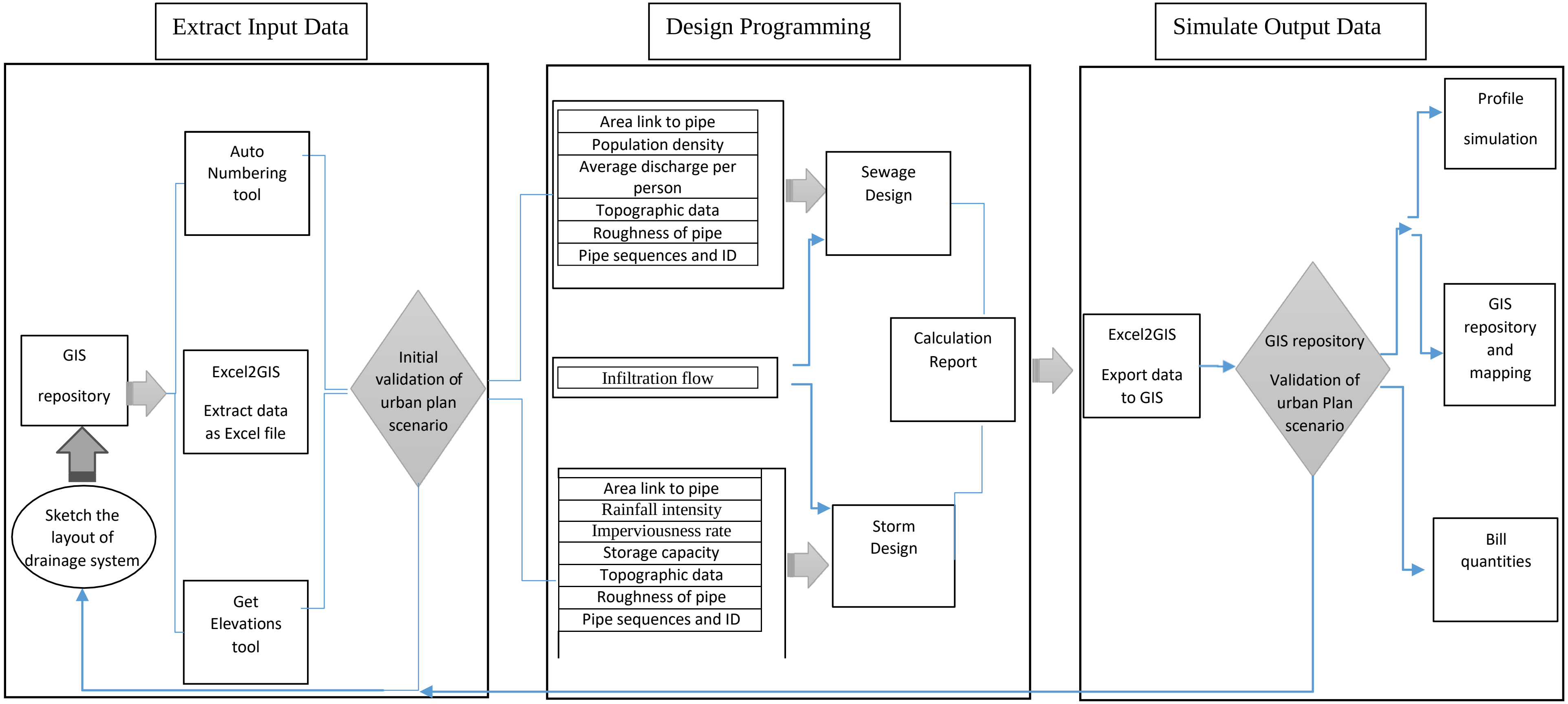

Fig. 1. Flowcharts showing the structure of the embedded tools in the model for extracting input data of an urban drainage system’s design.

Figure 2 (a)

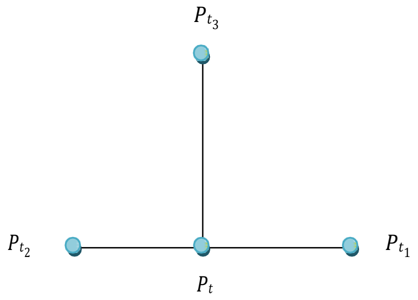

Fig. 2. The innovative software used for numbering the system (a) Sketch of manhole numbering process in the tool.

Figure 2 (b)

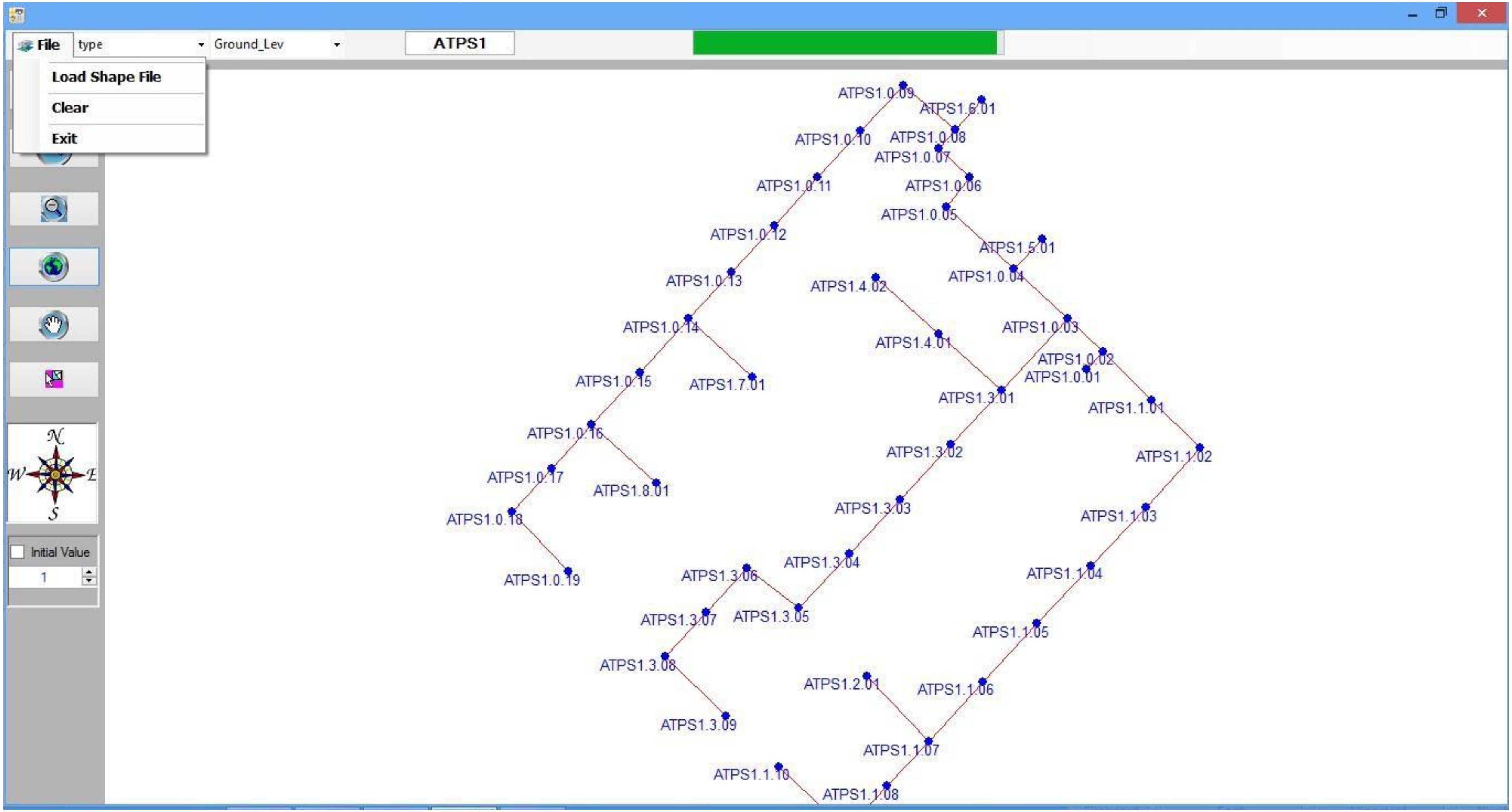

Fig. 2. The innovative software used for numbering the system (b) Interface of the Auto Numbering software tool.

Figure 3

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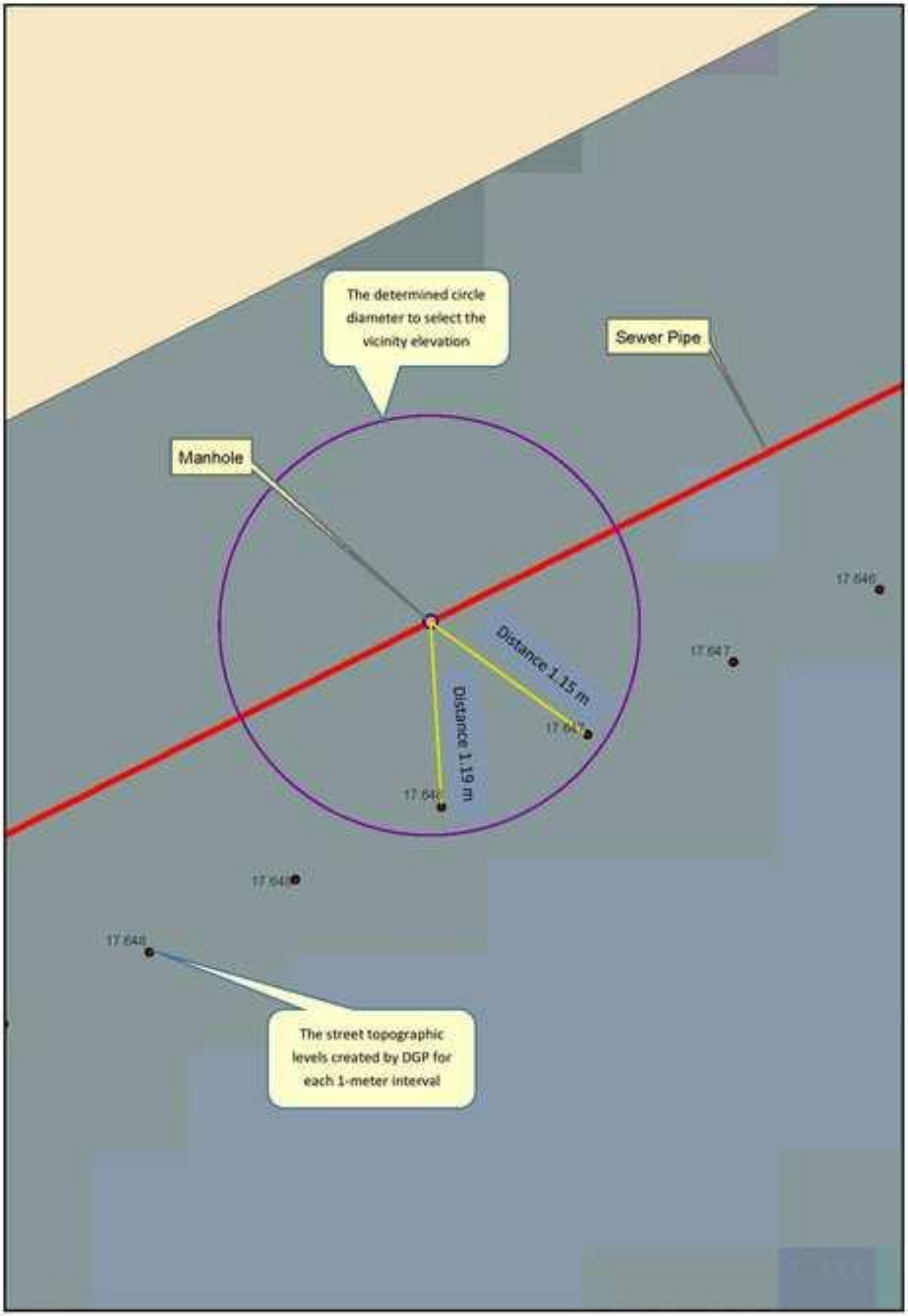

Figure 4

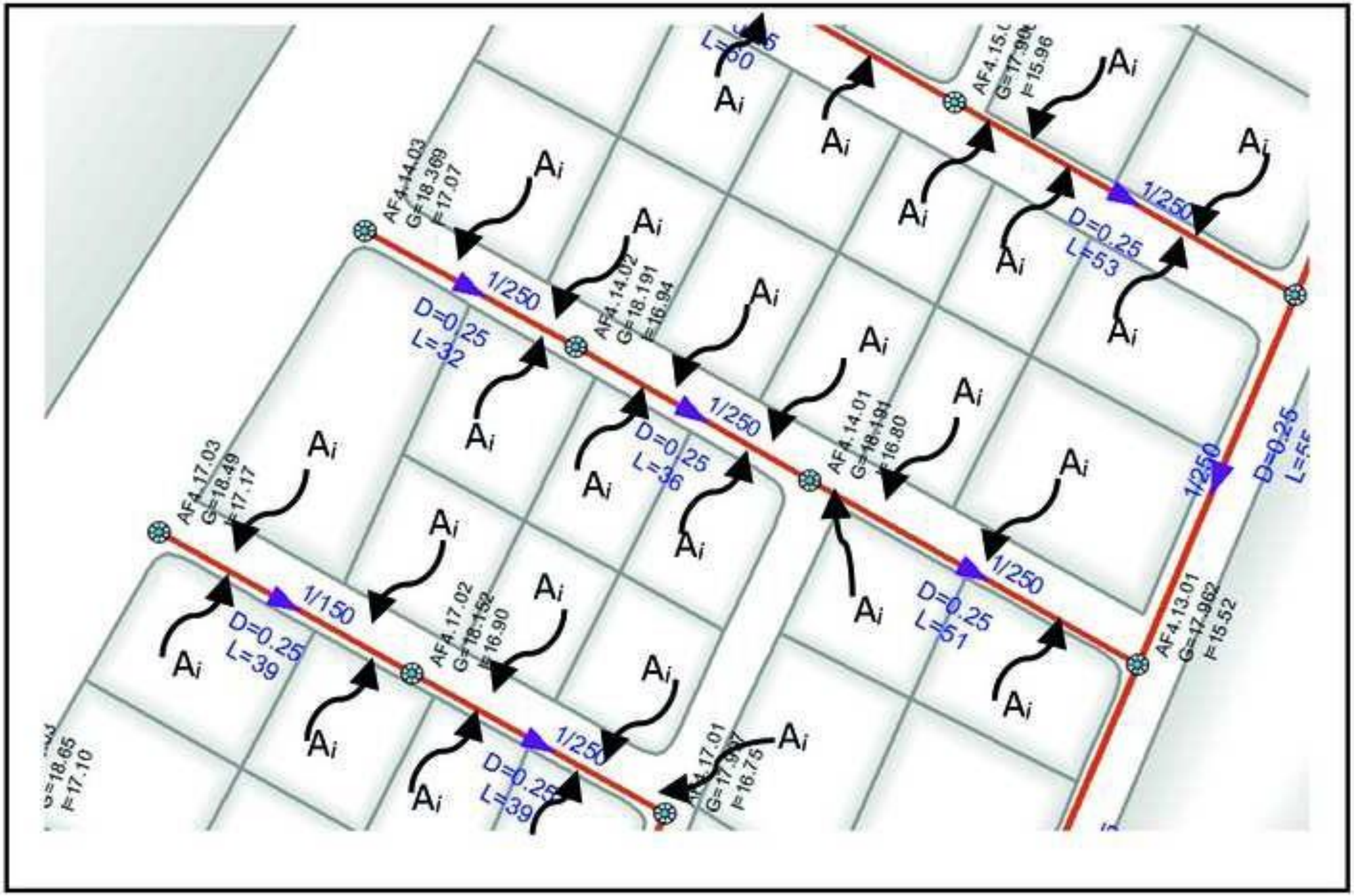
AF4.14.03
G=18.369
I=17.07
1/250
D=0.25
L=32
AF4.14.02
G=18.191
I=16.94
1/250
D=0.25
L=36
AF4.14.01
G=18.191
I=16.80
1/250
D=0.25
L=51
AF4.13.01
G=17.962
I=15.52
1/250
D=0.25
AF4.15.0
G=17.96
I=15.96
1/250
D=0.25
L=53
AF4.17.03
G=18.49
I=17.17
1/150
D=0.25
L=39
AF4.17.02
G=18.152
I=16.90
1/250
D=0.25
L=39
AF4.17.01
I=16.75
G=18.65
I=17.10
A$_i$

Figure 5 (a)

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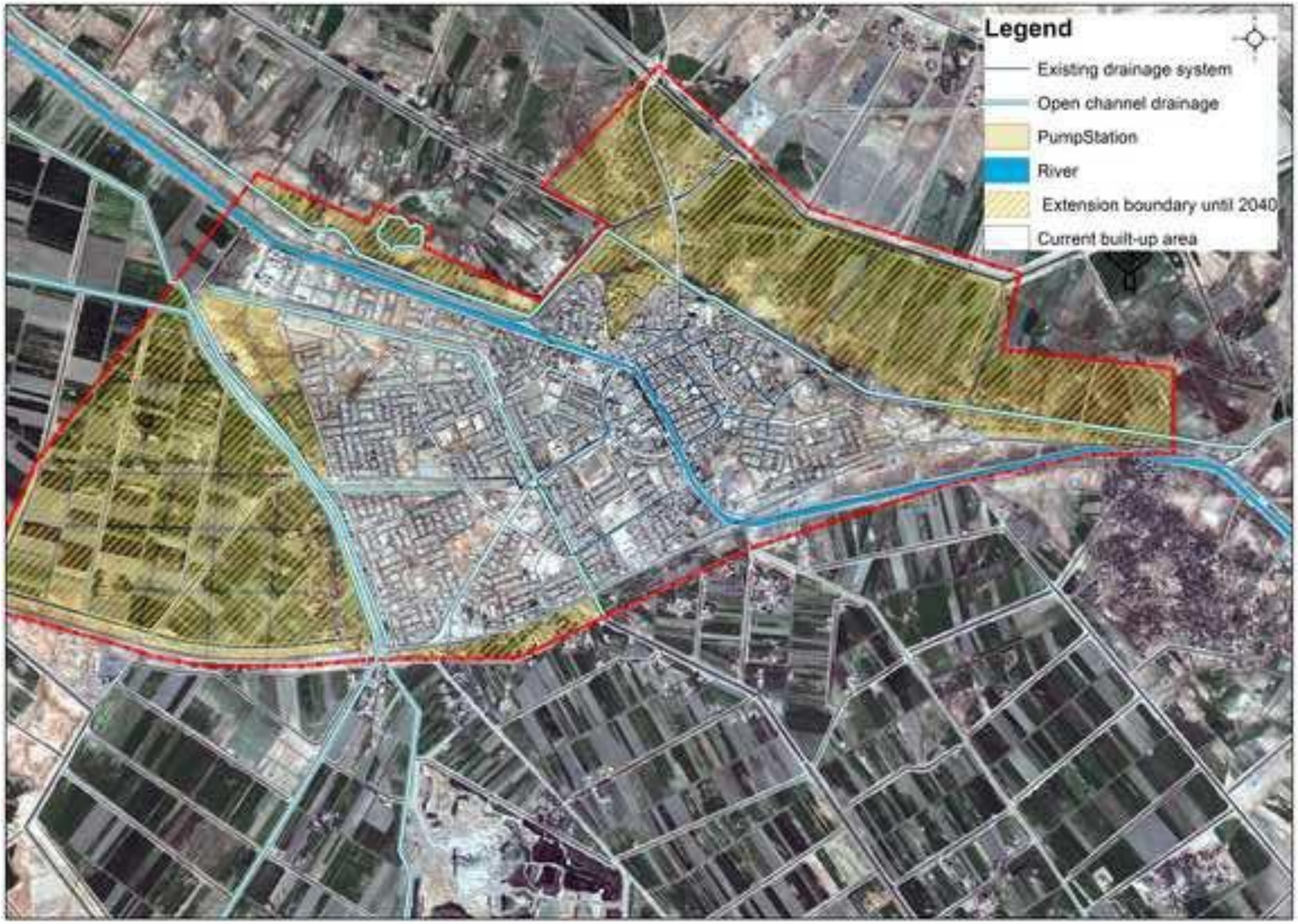

Figure 5 (b)

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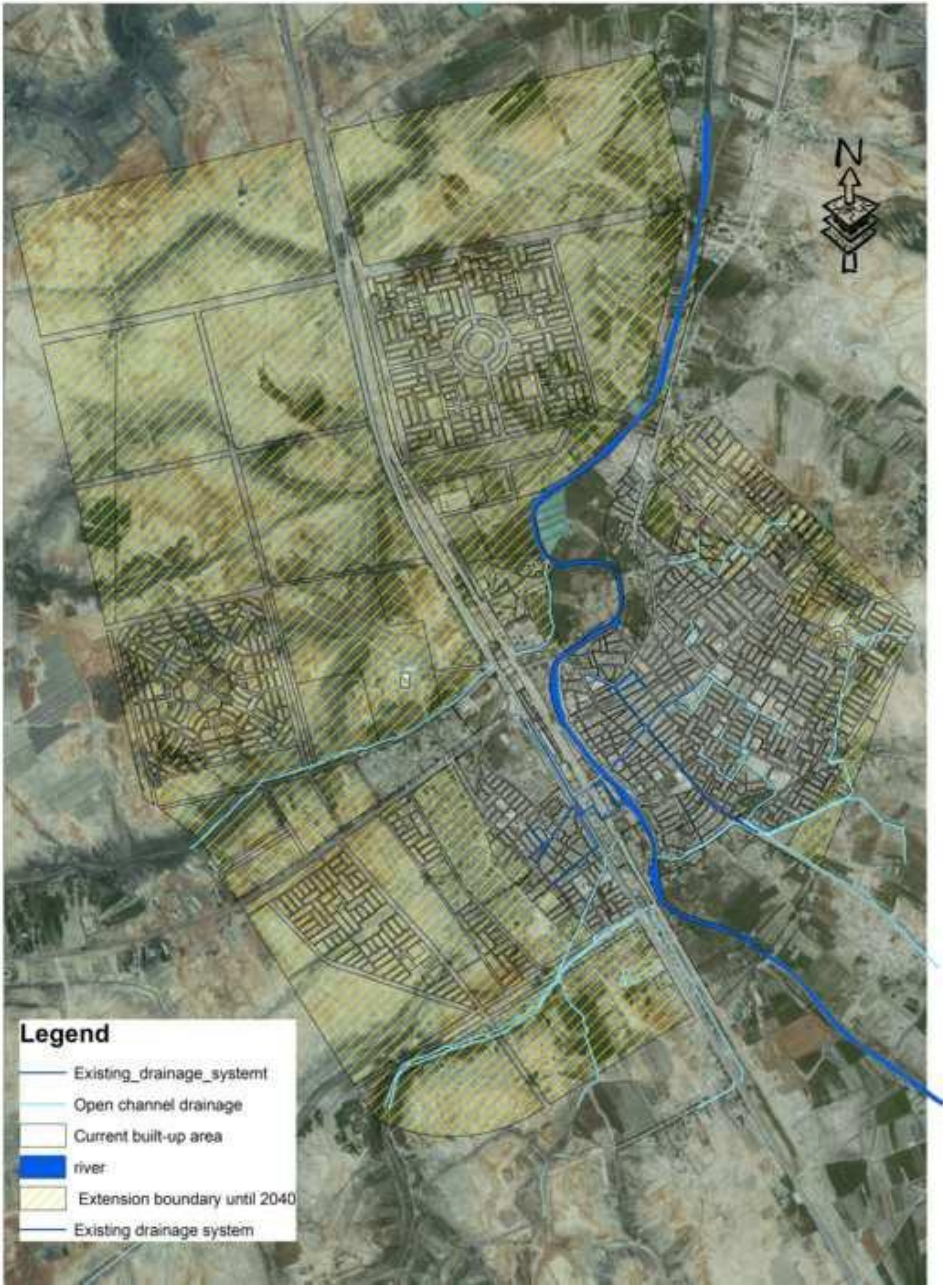

Figure 6 (a)

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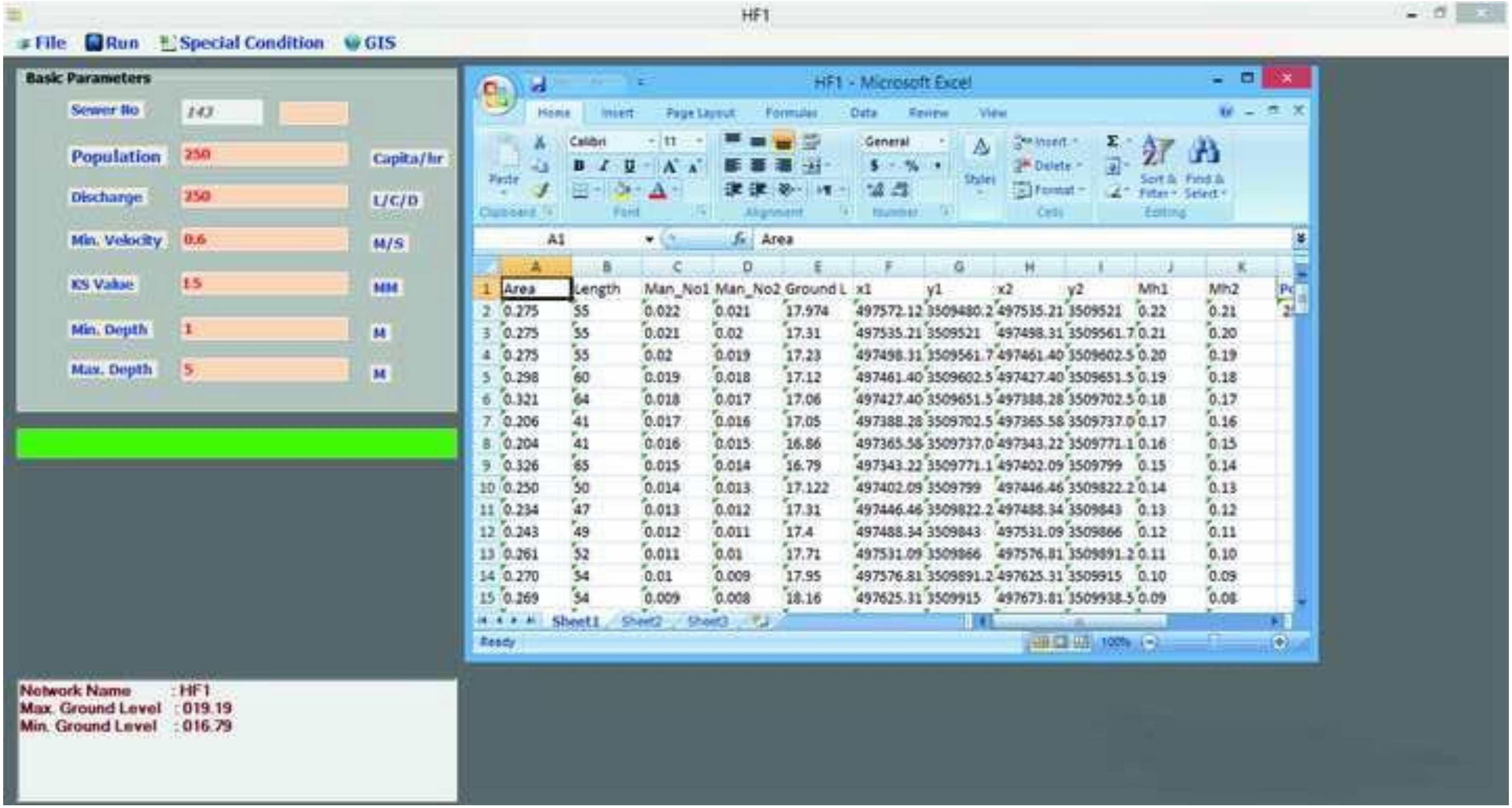


Basic Parameters

Sewer No 143

Population 250 Capita/hr

Discharge 250 L/C/D

Min. Velocity 0.6 M/S

KS Value 1.5 MM

Min. Depth 1 M

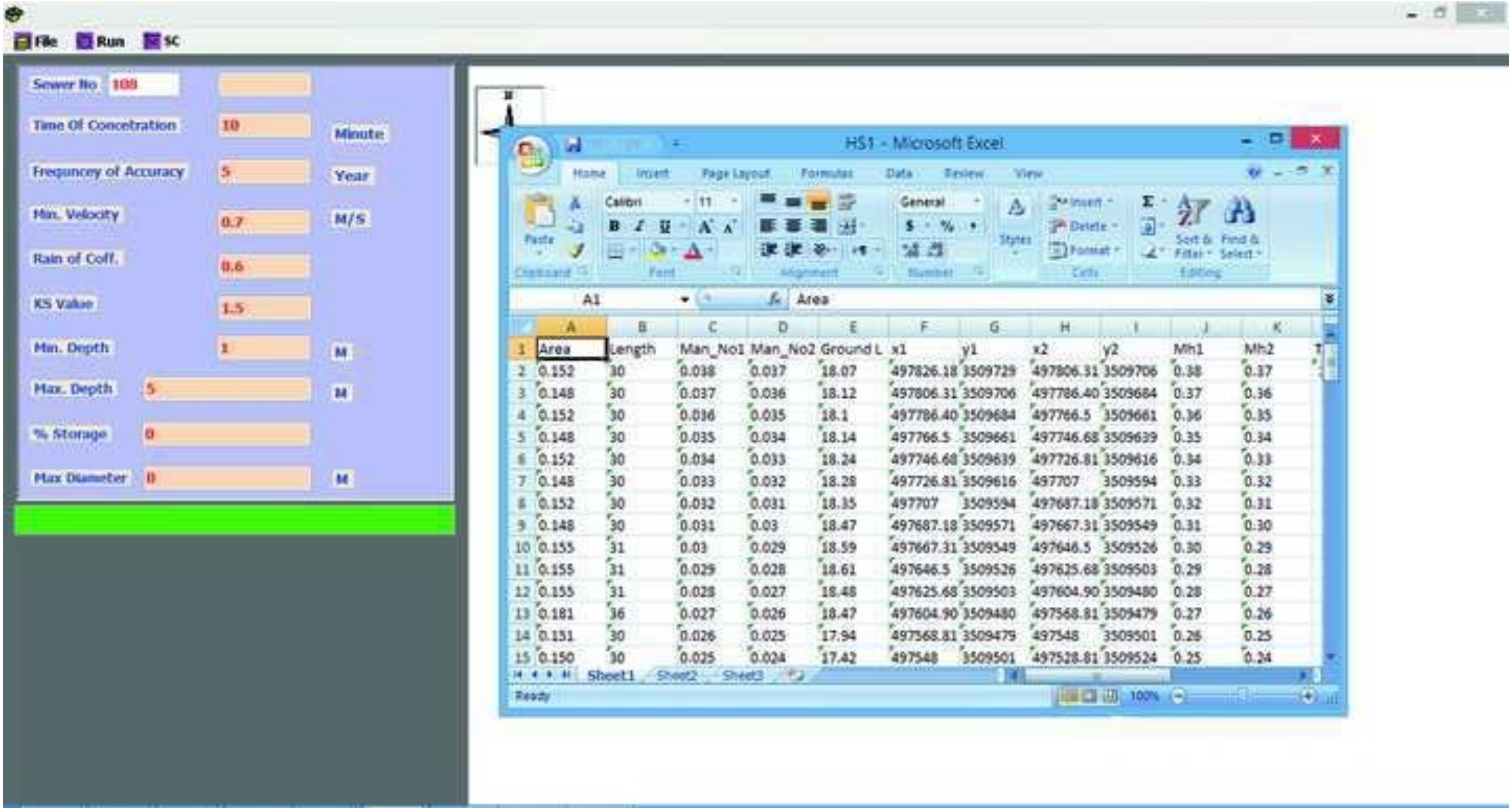
Max. Depth 5 M

A1 Area

	A	B	C	D	E	F	G	H	I	J	K	
1	Area	Length	Man_No1	Man_No2	Ground L	x1	y1	x2	y2	Mh1	Mh2	Pc
2	0.275	55	0.022	0.021	17.974	497572.12	3509480.2	497535.21	3509521	0.22	0.21	2
3	0.275	55	0.021	0.02	17.31	497535.21	3509521	497498.31	3509561.7	0.21	0.20	
4	0.275	55	0.02	0.019	17.23	497498.31	3509561.7	497461.40	3509602.5	0.20	0.19	
5	0.298	60	0.019	0.018	17.12	497461.40	3509602.5	497427.40	3509651.5	0.19	0.18	
6	0.321	64	0.018	0.017	17.06	497427.40	3509651.5	497388.28	3509702.5	0.18	0.17	
7	0.206	41	0.017	0.016	17.05	497388.28	3509702.5	497365.58	3509737.0	0.17	0.16	
8	0.204	41	0.016	0.015	16.86	497365.58	3509737.0	497343.22	3509771.1	0.16	0.15	
9	0.326	65	0.015	0.014	16.79	497343.22	3509771.1	497402.09	3509799	0.15	0.14	
10	0.250	50	0.014	0.013	17.122	497402.09	3509799	497446.46	3509822.2	0.14	0.13	
11	0.234	47	0.013	0.012	17.31	497446.46	3509822.2	497488.34	3509843	0.13	0.12	
12	0.243	49	0.012	0.011	17.4	497488.34	3509843	497531.09	3509866	0.12	0.11	
13	0.261	52	0.011	0.01	17.71	497531.09	3509866	497576.81	3509891.2	0.11	0.10	
14	0.270	54	0.01	0.009	17.95	497576.81	3509891.2	497625.31	3509915	0.10	0.09	
15	0.269	54	0.009	0.008	18.16	497625.31	3509915	497673.81	3509938.5	0.09	0.08	

Network Name : HF1
Max. Ground Level : 019.19
Min. Ground Level : 016.79

Figure 6 (b)



Sewer No 108

Time Of Concetration 10 Minute

Frequncey of Accuracy 5 Year

Min. Velocity 0.7 M/S

Rain of Coff. 0.6

KS Value 1.5

Min. Depth 1 M

Max. Depth 5 M

% Storage 0

Max Diameter 0 M

A1 Area

	A	B	C	D	E	F	G	H	I	J	K
1	Area	Length	Man_No1	Man_No2	Ground L	x1	y1	x2	y2	Mh1	Mh2
2	0.152	30	0.038	0.037	18.07	497826.18	3509729	497806.31	3509706	0.38	0.37
3	0.148	30	0.037	0.036	18.12	497806.31	3509706	497786.40	3509684	0.37	0.36
4	0.152	30	0.036	0.035	18.1	497786.40	3509684	497766.5	3509661	0.36	0.35
5	0.148	30	0.035	0.034	18.14	497766.5	3509661	497746.68	3509639	0.35	0.34
6	0.152	30	0.034	0.033	18.24	497746.68	3509639	497726.81	3509616	0.34	0.33
7	0.148	30	0.033	0.032	18.28	497726.81	3509616	497707	3509594	0.33	0.32
8	0.152	30	0.032	0.031	18.35	497707	3509594	497687.18	3509571	0.32	0.31
9	0.148	30	0.031	0.03	18.47	497687.18	3509571	497667.31	3509549	0.31	0.30
10	0.155	31	0.03	0.029	18.59	497667.31	3509549	497646.5	3509526	0.30	0.29
11	0.155	31	0.029	0.028	18.61	497646.5	3509526	497625.68	3509503	0.29	0.28
12	0.155	31	0.028	0.027	18.48	497625.68	3509503	497604.90	3509480	0.28	0.27
13	0.181	36	0.027	0.026	18.47	497604.90	3509480	497568.81	3509479	0.27	0.26
14	0.151	30	0.026	0.025	17.94	497568.81	3509479	497548	3509501	0.26	0.25
15	0.150	30	0.025	0.024	17.42	497548	3509501	497528.81	3509524	0.25	0.24

Figure 7.

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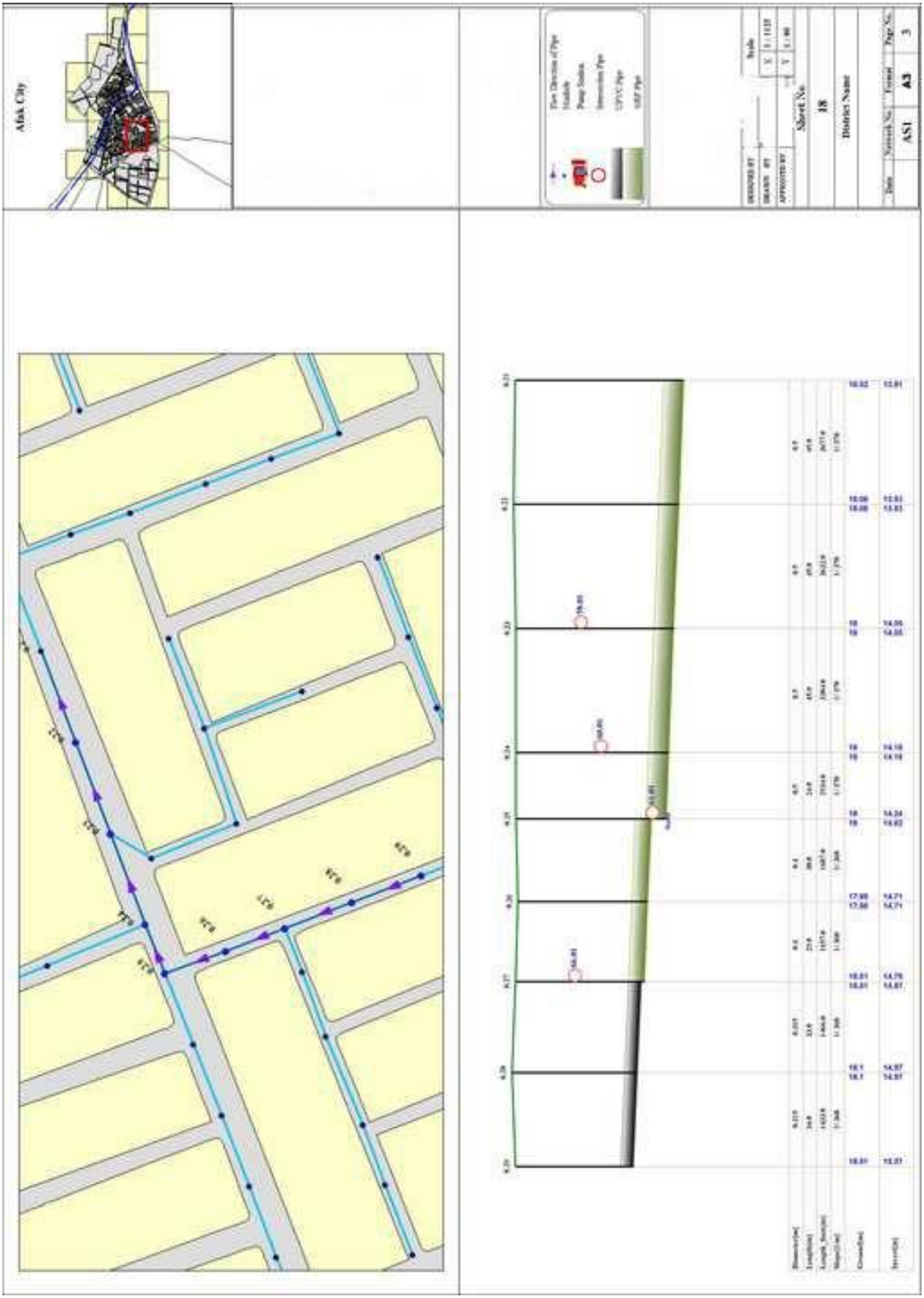
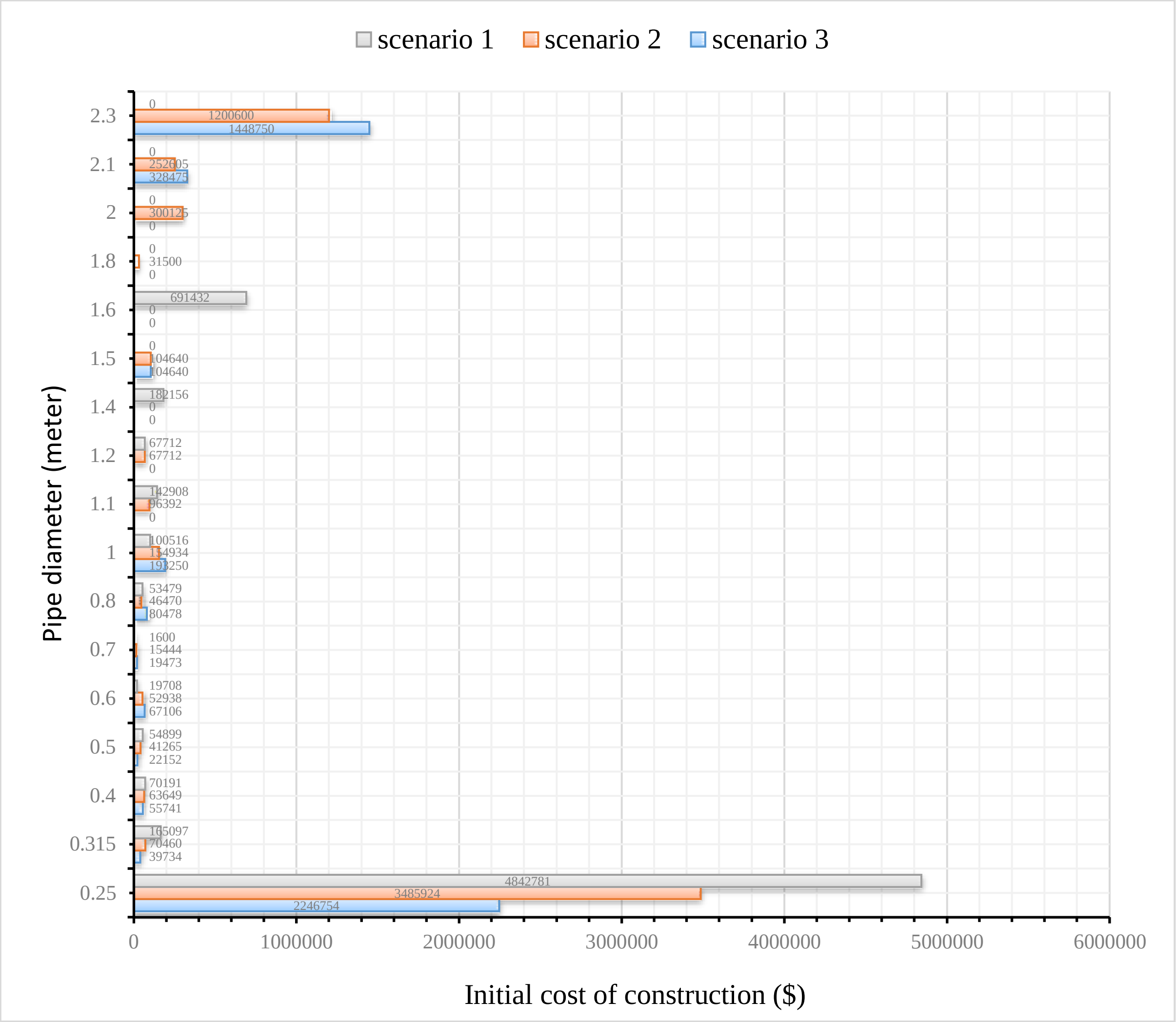


Figure 8 (a)



□ scenario 1
□ scenario 2
□ scenario 3
Pipe diameter (meter)
2.3
2.1
2
1.8
1.6
1.5
1.4
1.2
1.1
1
0.8
0.7
0.6
0.5
0.4
0.315
0.25
0
1200600
1448750
0
252605
328475
0
300125
0
0
31500
0
691432
0
0
0
104640
104640
182156
0
0
67712
67712
0
142908
96392
0
100516
154934
193250
53479
46470
80478
1600
15444
19473
19708
52938
67106
54899
41265
22152
70191
63649
55741
165097
70460
39734
4842781
3485924
2246754
0
1000000
2000000
3000000
4000000
5000000
6000000
Initial cost of construction ($)

Figure 8 (b)

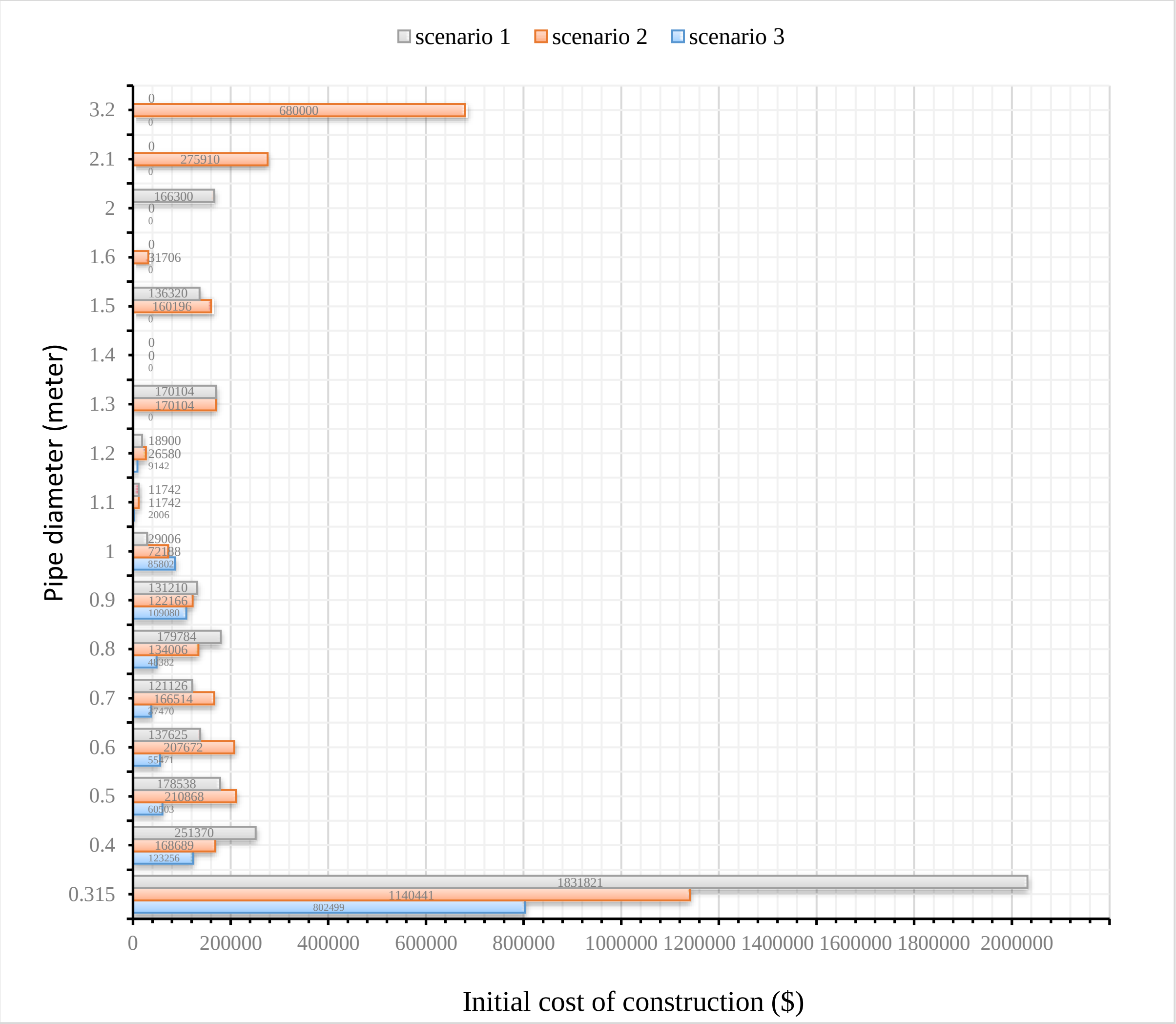

□ scenario 1 □ scenario 2 □ scenario 3
Pipe diameter (meter)
3.2
0
680000
0
2.1
0
275910
0
2
166300
0
0
1.6
0
31706
0
1.5
136320
160196
0
1.4
0
0
0
1.3
170104
170104
0
1.2
18900
26580
9142
1.1
11742
11742
2006
1
29006
72188
85802
0.9
131210
122166
109080
0.8
179784
134006
48382
0.7
121126
166514
37470
0.6
137625
207672
55471
0.5
178538
210868
60503
0.4
251370
168689
123256
0.315
1831821
1140441
802499
0
200000
400000
600000
800000
1000000
1200000
1400000
1600000
1800000
2000000
Initial cost of construction ($)

Figure 9 (a)

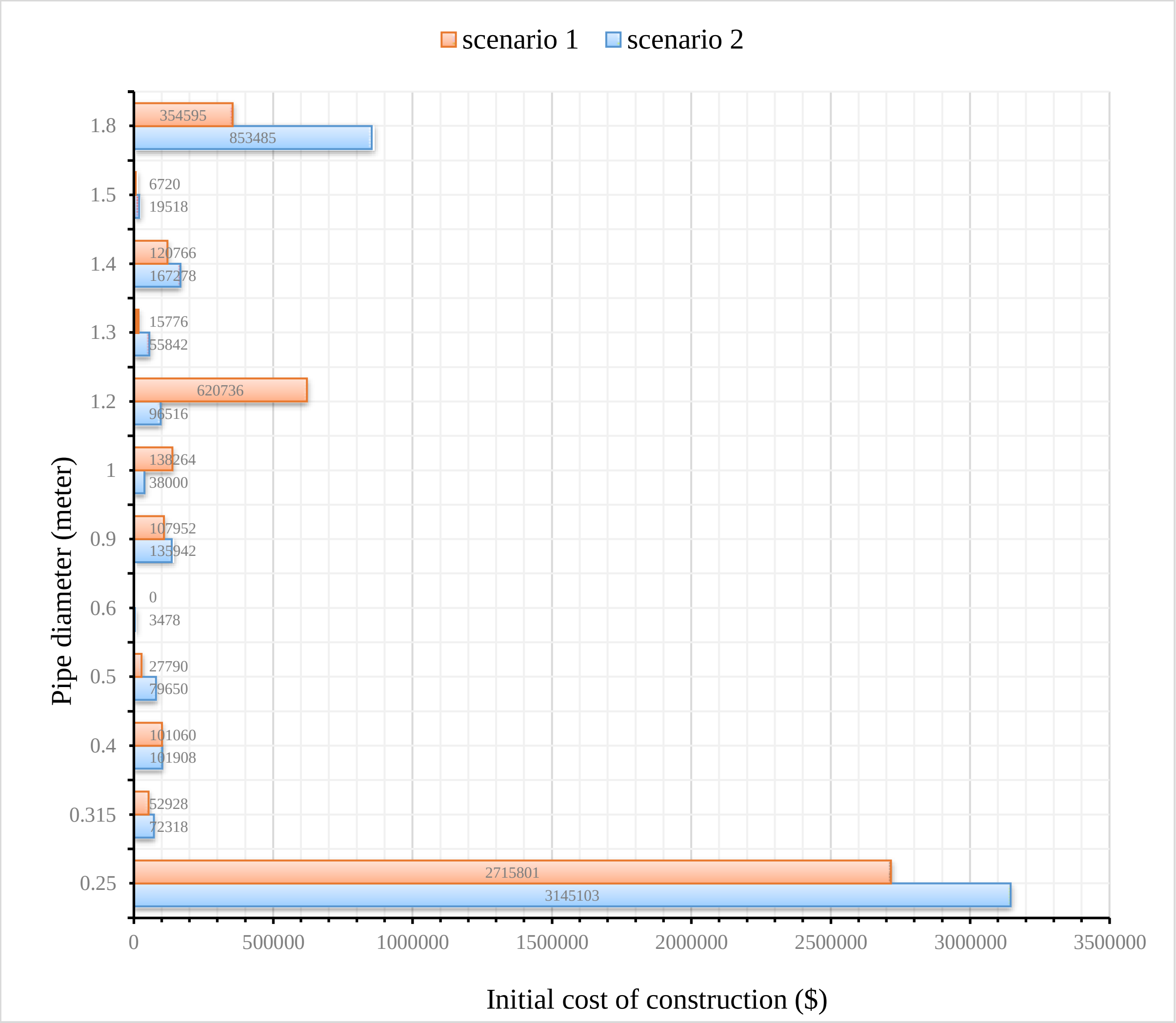

scenario 1
scenario 2
Pipe diameter (meter)
1.8
354595
853485
1.5
6720
19518
1.4
120766
167278
1.3
15776
55842
1.2
620736
96516
1
138264
38000
0.9
107952
135942
0.6
0
3478
0.5
27790
79650
0.4
101060
101908
0.315
52928
72318
0.25
2715801
3145103
0
500000
1000000
1500000
2000000
2500000
3000000
3500000
Initial cost of construction ($)

Figure 9 (b)

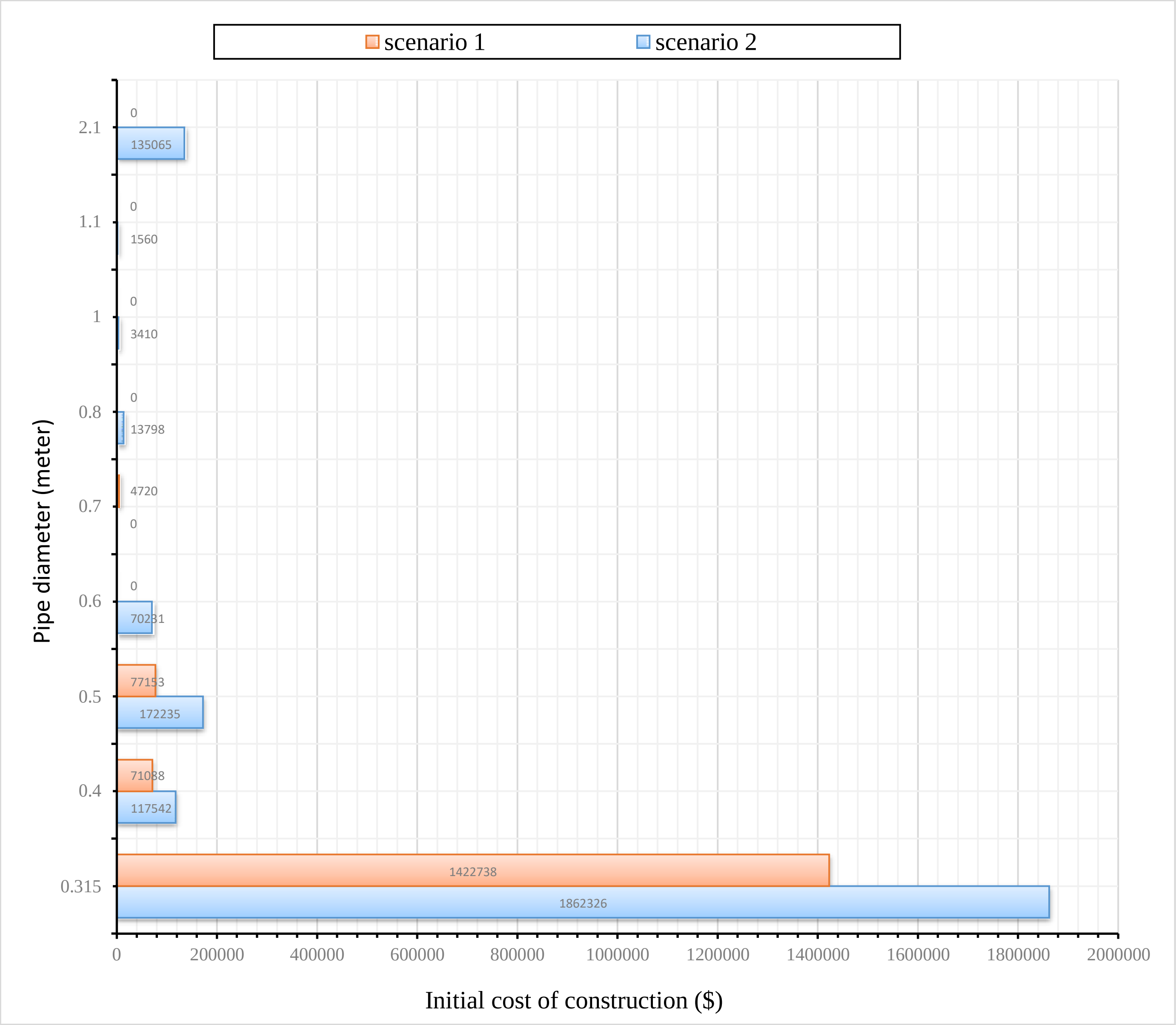

scenario 1
scenario 2
Pipe diameter (meter)
2.1
1.1
1
0.8
0.7
0.6
0.5
0.4
0.315
0
135065
0
1560
0
3410
0
13798
4720
0
0
70231
77153
172235
71088
117542
1422738
1862326
0
200000
400000
600000
800000
1000000
1200000
1400000
1600000
1800000
2000000
Initial cost of construction ($)

Figure 10 (a)

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Figure 10 (b)

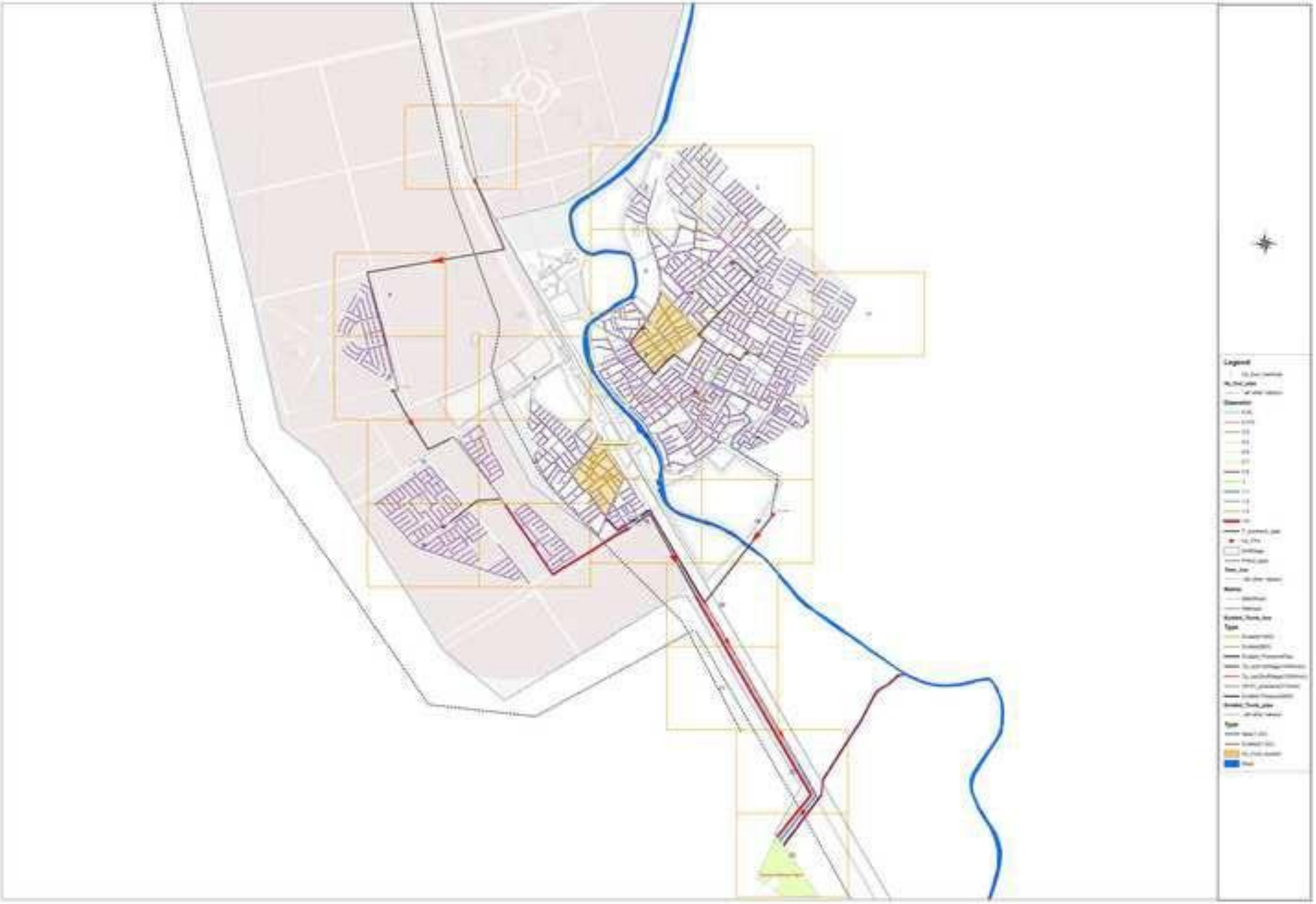
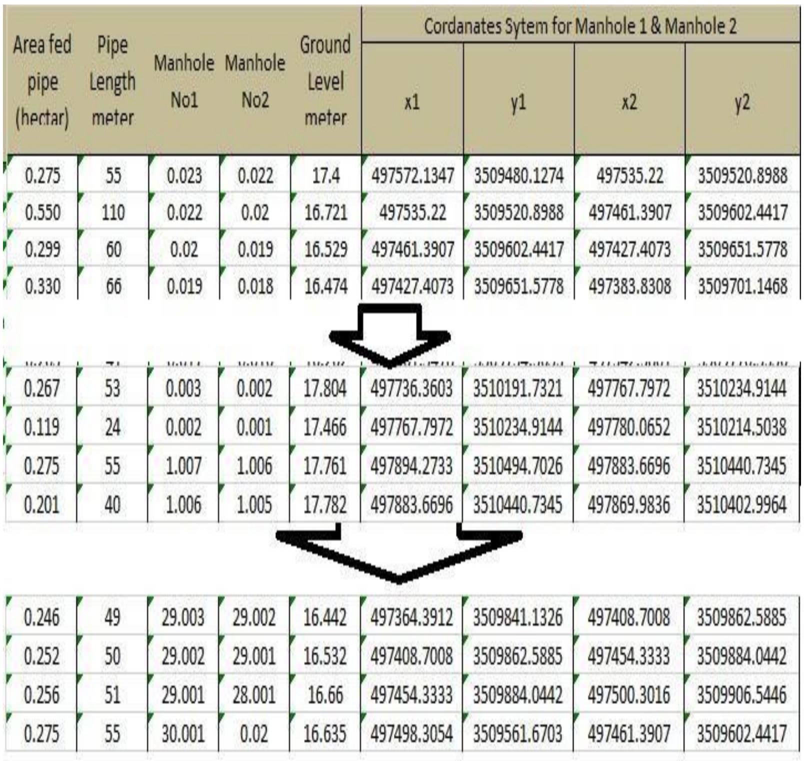


Table 1

Table 1

Input file extracted from GIS.



Area fed pipe (hectar)	Pipe Length meter	Manhole No1	Manhole No2	Ground Level meter	Cordanates Sytem for Manhole 1 & Manhole 2			
					x1	y1	x2	y2
0.275	55	0.023	0.022	17.4	497572.1347	3509480.1274	497535.22	3509520.8988
0.550	110	0.022	0.02	16.721	497535.22	3509520.8988	497461.3907	3509602.4417
0.299	60	0.02	0.019	16.529	497461.3907	3509602.4417	497427.4073	3509651.5778
0.330	66	0.019	0.018	16.474	497427.4073	3509651.5778	497383.8308	3509701.1468
0.267	53	0.003	0.002	17.804	497736.3603	3510191.7321	497767.7972	3510234.9144
0.119	24	0.002	0.001	17.466	497767.7972	3510234.9144	497780.0652	3510214.5038
0.275	55	1.007	1.006	17.761	497894.2733	3510494.7026	497883.6696	3510440.7345
0.201	40	1.006	1.005	17.782	497883.6696	3510440.7345	497869.9836	3510402.9964
0.246	49	29.003	29.002	16.442	497364.3912	3509841.1326	497408.7008	3509862.5885
0.252	50	29.002	29.001	16.532	497408.7008	3509862.5885	497454.3333	3509884.0442
0.256	51	29.001	28.001	16.66	497454.3333	3509884.0442	497500.3016	3509906.5446
0.275	55	30.001	0.02	16.635	497498.3054	3509561.6703	497461.3907	3509602.4417

Table 2

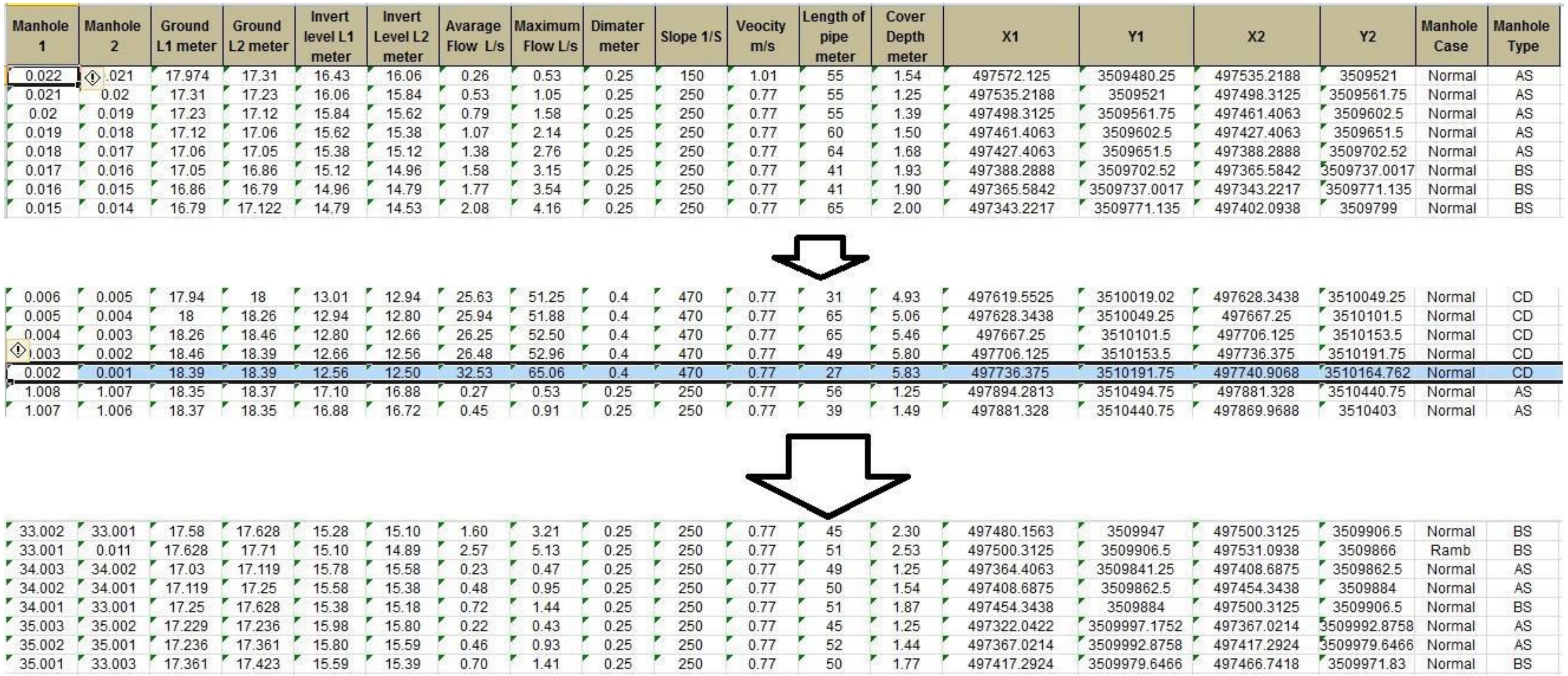
The features of the two case study sites (two cities in Iraq).

City	Population (capita)		Area (hectares)		Annual Precipitation (mm)		
	Current	Extension	Current	Extension	Average	Max.	Min.
Afak	29228	72125	320	249	116.84	271.78	45.72
Al Hamza	71346	111251	267	1307	116.84	271.78	45.72

Table 3

Table 3

Sample of calculation results data file.



Manhole 1	Manhole 2	Ground L1 meter	Ground L2 meter	Invert level L1 meter	Invert Level L2 meter	Avarage Flow L/s	Maximum Flow L/s	Dimater meter	Slope 1/S	Veocity m/s	Length of pipe meter	Cover Depth meter	X1	Y1	X2	Y2	Manhole Case	Manhole Type
0.022	.021	17.974	17.31	16.43	16.06	0.26	0.53	0.25	150	1.01	55	1.54	497572.125	3509480.25	497535.2188	3509521	Normal	AS
0.021	0.02	17.31	17.23	16.06	15.84	0.53	1.05	0.25	250	0.77	55	1.25	497535.2188	3509521	497498.3125	3509561.75	Normal	AS
0.02	0.019	17.23	17.12	15.84	15.62	0.79	1.58	0.25	250	0.77	55	1.39	497498.3125	3509561.75	497461.4063	3509602.5	Normal	AS
0.019	0.018	17.12	17.06	15.62	15.38	1.07	2.14	0.25	250	0.77	60	1.50	497461.4063	3509602.5	497427.4063	3509651.5	Normal	AS
0.018	0.017	17.06	17.05	15.38	15.12	1.38	2.76	0.25	250	0.77	64	1.68	497427.4063	3509651.5	497388.2888	3509702.52	Normal	AS
0.017	0.016	17.05	16.86	15.12	14.96	1.58	3.15	0.25	250	0.77	41	1.93	497388.2888	3509702.52	497365.5842	3509737.0017	Normal	BS
0.016	0.015	16.86	16.79	14.96	14.79	1.77	3.54	0.25	250	0.77	41	1.90	497365.5842	3509737.0017	497343.2217	3509771.135	Normal	BS
0.015	0.014	16.79	17.122	14.79	14.53	2.08	4.16	0.25	250	0.77	65	2.00	497343.2217	3509771.135	497402.0938	3509799	Normal	BS
0.006	0.005	17.94	18	13.01	12.94	25.63	51.25	0.4	470	0.77	31	4.93	497619.5525	3510019.02	497628.3438	3510049.25	Normal	CD
0.005	0.004	18	18.26	12.94	12.80	25.94	51.88	0.4	470	0.77	65	5.06	497628.3438	3510049.25	497667.25	3510101.5	Normal	CD
0.004	0.003	18.26	18.46	12.80	12.66	26.25	52.50	0.4	470	0.77	65	5.46	497667.25	3510101.5	497706.125	3510153.5	Normal	CD
.003	0.002	18.46	18.39	12.66	12.56	26.48	52.96	0.4	470	0.77	49	5.80	497706.125	3510153.5	497736.375	3510191.75	Normal	CD
0.002	0.001	18.39	18.39	12.56	12.50	32.53	65.06	0.4	470	0.77	27	5.83	497736.375	3510191.75	497740.9068	3510164.762	Normal	CD
1.008	1.007	18.35	18.37	17.10	16.88	0.27	0.53	0.25	250	0.77	56	1.25	497894.2813	3510494.75	497881.328	3510440.75	Normal	AS
1.007	1.006	18.37	18.35	16.88	16.72	0.45	0.91	0.25	250	0.77	39	1.49	497881.328	3510440.75	497869.9688	3510403	Normal	AS
33.002	33.001	17.58	17.628	15.28	15.10	1.60	3.21	0.25	250	0.77	45	2.30	497480.1563	3509947	497500.3125	3509906.5	Normal	BS
33.001	0.011	17.628	17.71	15.10	14.89	2.57	5.13	0.25	250	0.77	51	2.53	497500.3125	3509906.5	497531.0938	3509866	Ramb	BS
34.003	34.002	17.03	17.119	15.78	15.58	0.23	0.47	0.25	250	0.77	49	1.25	497364.4063	3509841.25	497408.6875	3509862.5	Normal	AS
34.002	34.001	17.119	17.25	15.58	15.38	0.48	0.95	0.25	250	0.77	50	1.54	497408.6875	3509862.5	497454.3438	3509884	Normal	AS
34.001	33.001	17.25	17.628	15.38	15.18	0.72	1.44	0.25	250	0.77	51	1.87	497454.3438	3509884	497500.3125	3509906.5	Normal	BS
35.003	35.002	17.229	17.236	15.98	15.80	0.22	0.43	0.25	250	0.77	45	1.25	497322.0422	3509997.1752	497367.0214	3509992.8758	Normal	AS
35.002	35.001	17.236	17.361	15.80	15.59	0.46	0.93	0.25	250	0.77	52	1.44	497367.0214	3509992.8758	497417.2924	3509979.6466	Normal	AS
35.001	33.003	17.361	17.423	15.59	15.39	0.70	1.41	0.25	250	0.77	50	1.77	497417.2924	3509979.6466	497466.7418	3509971.83	Normal	BS

Table 4

Installation cost of the sewer systems for each scenario of Al Hamza city and Afak city.

	Estimated construction cost ($)				
	Al Hamza City			Afak City	
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2
Wastewater system	6392479	5984658	4606553	4262388	4769038
Stormwater system	3363846	3578782	1333611	1575699	2376167