Integrated Triangular Irregular Network (ITIN) Model for Flood Plain Analysis

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Abstract
Flood inundation extent is highly dependent on topography. Therefore, shallow flood plain gradients means that small errors in modelled water surface elevations may lead to large errors in the predicted inundation extend. The foundation for detailed modelling requires an accurate GIS based Multi-resolution terrain model which only can be achieved through the usage of state-of-the art technologies. However, the present research presented here in introduces an integrated procedure for creating a high resolution integrated multi-resolution triangular irregular network model (ITIN) by utilising existing GIS tools. The constructed ITIN model was later used for extracting geometric data to feed the hydraulic modelling requirements, which were used in the flood risk analysis. The proposed method here can be very useful for hydrologic and hydraulic modellers and researchers with a limited access to high end GIS technologies.

1. Introduction

Terrain models can be classified into two types: Digital Elevation Model (DEM) and Triangulated Irregular Network (TIN) Model (De Floriani and Magillo, 2001, Magillo et al., 2000, De Floriani, 1996 and Sinnakaudan, 2003[b]). TIN is a finite set of points, which are stored with their elevation. The model is a piecewise linear model that in 3 dimensional space can be visualize as a simply connected set of triangles (De Berg, 2000 and Van Kreveld, 2000). The hierarchical or multi-resolution TIN model allows a mixture of different detail levels in parts of the terrain, which are very much suitable for flood plain analysis (Leenaers and Okx, 1989, Sinnakaudan, 2003[b], Sinnakaudan et al., 2002[a] and Van Kreveld, 2000). In contrast, the data structure in DEM consists of a matrix of equally spaced elevation values (mesh points) (Sole and Valanzano, 1996). Generally speaking, a DEM is easier to be constructed than a TIN, but for a multi-resolution terrain model development for flood risk analysis, where the level of detail may be different in distinct areas of the object, DEM structure may have the problem of terrain tearing between tiles with different resolutions (Anrysiak, 2000, Leenaers and Okx, 1989 and Sinnakaudan, and Rainis, 1999). Thus, usage of a TIN constructed from a wide source of reliable elevation data is the most preferred choice in terrain model construction and visualization (Sinnakaudan et al., 2002[a] and Magillo et al., 2000). Constructing a continuous floodplain terrain model with a high density of stream channel elevation points sufficient for hydraulic modelling

are cost intensive and the required input data are generally not available (Sinnakaudan et al., 2002[a]). However for years, engineers and researchers have gathered high-resolution cross-section data for hydraulic modelling from field surveys, construction plans and photogrammetric techniques (Anrysiak, P.B., 2000, De Berg, M., 2000, Leenaers, and Okx, 1989 and Sinnakaudan et al., 2002[a]). Sinnakaudan et al., (2002) have demonstrated the possibilities of integrating high-resolution channel elevation information available in HEC-6 model and low-resolution flood plain elevation data from DEM (Sinnakaudan et al., 2003[a], Sinnakaudan, 2003[b] and Sinnakaudan et al., 2002[a]). However, a main problem arises when a spatial-hydraulic modeller try to use the spatial capabilities of GIS to generate directly the required data for hydraulic models. The GIS database structure exists in spatial entities linked to attribute table. However, most of the function oriented hydraulic models such as SFlood model only can read the modelling data in structured ASCII file format (Sinnakaudan, 2003[b]). SFlood is the enhanced version of HEC-6, which has the capabilities for predicting flood levels incorporating sediment transport in Malaysian River Conditions (Sinnakaudan, 2003[b]). In the pre-processing stage, hydraulic modelling parameters need to be extracted from the GIS database to feed into SFlood model (Sinnakaudan, 2003[b]). The database differences need to be solved and the output file from the SFlood model need to be read in the post-processing stage, which are then transferred into series of flood

inundation maps. Beside that, SFlood and ArcView GIS have very significant differences in data handling and representation. In the SFlood reference system, the cross-sections referred as chainages, which are measured in feet and starts from downstream to the most upstream location of the stream. The coordinate of any cross section is based on 1D location along the cross-section line or in other words on series of station and elevation points along a cross section. In contrast, data in ArcView are well referenced with real world Rectified Skew Orthomorfic (RSO) map coordinates. The location of a given point in space is based on its east (x-coordinate), north (y-coordinate), and elevation (z-coordinate). SFlood does not have any graphic representation of the modeled river and solely based on distance calculations such as distance between points and each modelled cross section. However, ArcView represents rivers as a straight or curved line, which is based on its original condition of the study site (ESRI, 1996 and ESRI, 1999). Thus in order to use SFlood and ArcView GIS, the difference of data formats between SFlood and ArcView GIS must be resolved. This is one of the fundamental problems solved in this study.

2. Data and Methodology

Integration of hydro-spatial features requires the acquirement of a great amount of accurate data. The process includes determining the data requirement, identifying the possible data sources, converting the data into appropriate format for the SFlood hydraulic model and output visualization. The study presented herein utilizes the elevation data derived from Pari River catchment in Ipoh, Perak, Malaysia (Figure 1) from various sources and formats as listed in Table 1. Quality control would be the most important task because results of the model would be dependent on the input data. The data for this research have been obtained from various sources such as Ipoh Municipal Council (MBI), Department of Irrigation and Drainage (DID) Kinta-Batang Padang, DID Hydrological Division at Jalan Ampang, private consultants and field spot height measurements. The data were processed using Arc View GIS 3.2 (including the Spatial and 3D Analyst extensions), PC ArcINFO and AutoCad. The initial step in data processing for this research is to determine that all the data has a common coordinate system.
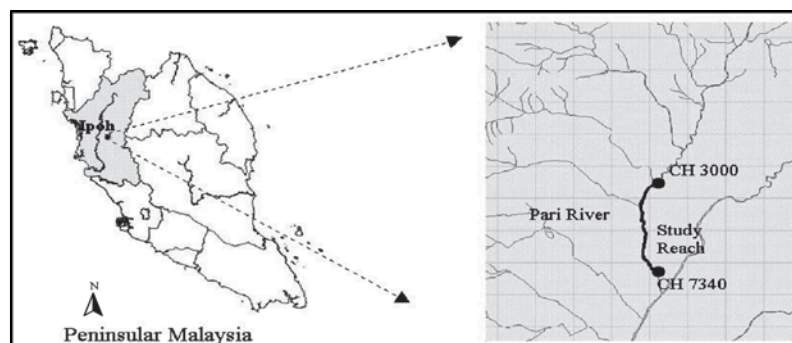

Figure 1: Study Area

Table 1: Data sources

Data Theme	Types of Data	Data Sources	Data Category
Ground surveys	- River surveys (20 meter section interval) - Finish Road Levels (FRL) - Finish Floor Level for buildings (FFL) - Invert Level (Drains and Waterways)	DID EDM Survey DID and EDM Survey	 Primary Data
Photogrammetry	Areial photographs Scale : 1: 10,000 Resolution : 3882 X 2539 pixels	DID, Engineering Consultants	Primary Data
Data Theme	Types of Data	Data Sources	Data Category
Existing maps	Topo Map - L 905 Series, Sheet Pk.1a – d, Scale 1: 10, 000 - L7030, Sheet 3562, Scale 1: 50, 000 - DNMM 8101 Series, Sheet - - Pk.1a – d, Scale 1: 10, 000 Lot Map for Pari River Scale 1: 10, 000	Universiti Sains Malaysia, Engineering Library	Secondary Data

The Rectified Skew Orthomorfic (RSO) coordinate system for Malaysia was utilized throughout the project. All the GIS themes and CAD drawings were projected into RSO system using ArcView GIS 3.2a and PC ARC/INFO. The main task is to establish an error free database with a minimal root mean square error. Each and every information obtained is to be represented in a series of cartographic layers (themes) or *coverages* which will be later entered into the system and assigning the spatial attributes by utilizing the relational database concept. A total of 213 cross sections which were surveyed with 20-meter interval on September 1999 were obtained from Department of Irrigation and Drainage Malaysia (DID). The lateral distance of the cross section is measured to the left and right of the bank station and the survey boundary established on the map. The elevation points along the cross section are plotted as a point shape file from the left bank to the right bank. The elevation value for each point was entered as attribute in the shape reference table (Figure 2). A total number of 1050 points were digitized to represent the cross sectional geometrical conditions of the study reach. The existing DID survey is limited to the area within the bund and not covering the flood plain. The Electronic Distance Measurement (EDM) survey was conducted to cover the entire study reach up to the extent of 1 km to the right and left of the thalweg line of Pari River. The reduced level (RL) of the surface elevation measured randomly with a very dense point measurement along the platforms, invert levels and places having abrupt changes in the surface elevation. Temporary Bench Mark (TBM) at Silibin Bridge with a reduced level of 38.58 meter was used as starting point for the EDM survey (Sinnakaudan, 2003_b). The collected points automatically converted into elevation point map. Another source of elevations data came from the Pari River Catchment contour maps which has 20 meter contour interval. These maps were screen digitized and topological properties are built before converting into point shape file. The elevation points are integrated into channel survey points in later stage for the construction of an Integrated Triangular Irregular Network (ITIN). The lot map, building footprint and road map which used as break lines in ITIN were obtained from various sources (Figure 3 and Figure 4) and geo-referenced to the aerial photograph (base map) of the study area, which was taken in the year 1999 (Figure 5). Polygon topology was built for buildings and the attribute information such as building name, location, photograph and height information was generated for further analysis.

A bounding polygon, called *modboundary* was used to define the study area's boundaries, defined as hard break lines to limit the ITIN within the modelling boundary. The point elevations were defined as *mass points* and the contour, lot, road, thalweg and river bank lines were defined as *soft break lines*. The soft break lines act as elevation input to the terrain model similar to the mass point data, but maintain continuous slope for the terrain's surface and mark the abrupt changes in the terrain. The usage of break lines can create a physical barrier to overland flows or high stage flows and may produce more dependable TINs for hydraulic model simulation and visualization (Sinnakaudan et al., 2002a). An ITIN may permit the modeller to extract automatically spatial information for any part of the study area. The automatic geometric data extraction operation was accomplished by the development of a Cross Section Records Extractor tool, which was created using ArcView GIS Avenue Scripts (Figure 6). The chainage location, position, and expanse of cross sections are represented by the Cross Section Cut Line theme. The channel geometry can be extracted at any point of the river channel bearing in mind the simulation capabilities of the SFlood model as described in the previous sections. The cross section cut lines preferably drawn perpendicular with the river thalweg line and only a maximum of 200 pairs of station and elevation coordinates will be extracted along each of the cut line. If a cut line intersects more than 200 ITIN triangle boundaries, only 200 nodes will be considered and the rest will be ignored to avoid the simulation error in SFlood model. The cross section cut lines cannot intersect to one another and should be placed perpendicular to the longitude of the river channel and flood plain. The cross section location must be representative of hydraulic characteristics of a reach and located at sites of historic high water marks or near areas of documented historic flood inundation which can later facilitate verification of the computed flood stage profiles. The sites for future development were considered in locating channel-flood plain cross sections. The 1D standard step procedures for water surface elevation calculation needs sufficient number of cross sections to satisfy two SFlood model requirements. First, a sufficient number of cross sections must be provided so that the geometric data of each stream reach, as represented by the cross sections, preserve the geometric and hydraulic properties of the prototype. Secondly, a sufficient number of cross sections must be provided to allow the model to correctly estimate the solution of the governing equations in discrete space.
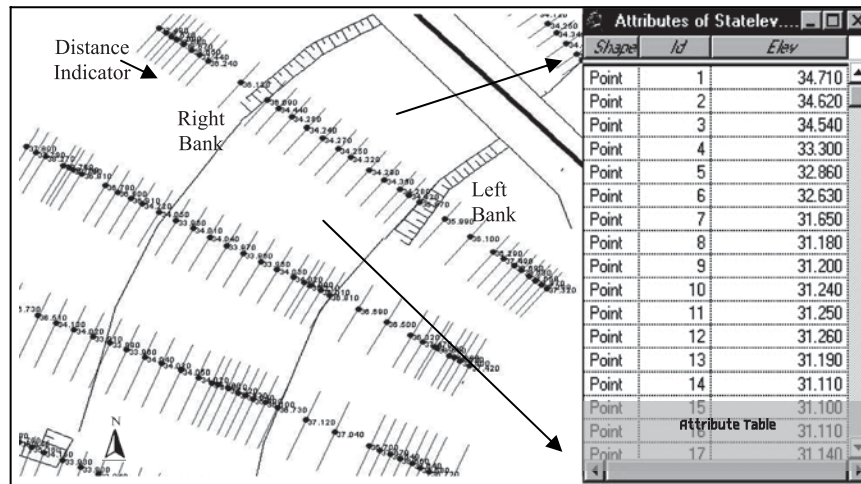
Figure 2: Digitizing bed elevation/cross section survey points

a. channel survey points

b. flood plain spot heights (EDM)

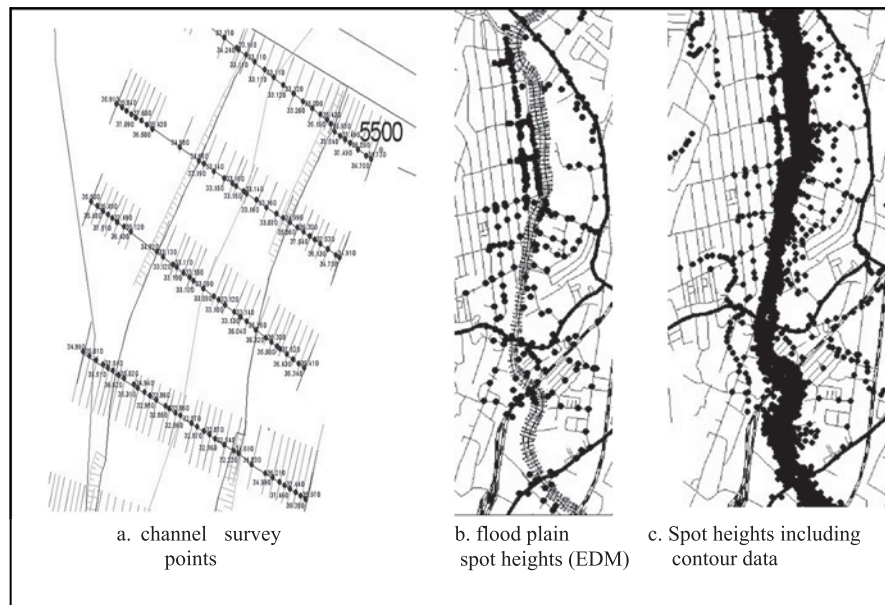c. Spot heights including contour data

Figure 3: The elevation point map created from various elevation sources for Pari catchment area

In general, three finite element ITIN meshes (ITIN1, ITIN2 and ITIN3) were constructed for this study using the same TIN generation method described above but with a different data configuration and flood plain extent (Figure 7 and 8). The input data to create the subsequent ITINs is summarized in Table 2. The construction of accurate ITIN terrain model is limited to study area that could be effectively used within the processing constraints of the computer. The practical limit to the number of triangles used in the ArcView GIS TIN mesh is 500, 000. The ITIN3 (Figure 9 and 10) yields most satisfactory cross section geometry compared to the other two ITINs and thus recommended for further analysis. The geometrical flexibility of the ITIN model allows to setting up of a mesh that represent many complexities of the Pari River catchment area, such as sharp building corners, roads, drains inverts and etc. The success of numerical modelling is directly related to the amount of accurate data available about the area. The modelling results seem to be strictly controlled by the bounding polygon created from the cross section data of the hydraulic model, and thus restrict the propagation of water over the flood plain beyond the extent of the cross section. This may cause the area vulnerable to flooding and will be completely ignored during the modelling process (Sinnakaudan et al., 2003[a]). This can be tackled by adding more cross section points for the flood plain. However, this may be limited due to the capabilities of the hydraulic model and GIS software used.

Table 2: ITIN configuration for geometric data extraction

ITIN Features	Extent of Modelling Geometry Data		
	ITIN 1	ITIN 2	ITIN 3
Input data	Channel geometry	Channel & Flood plain Geometry	Channel Survey, Flood plain Geometry, Break lines (buildings, roads, river banklines, thalweg line, and EDM survey Points)
Data	Flood plain assumed within the bund	Flood plain outside compound channel obtained from DEM data Extent: 200 meter buffered from Thalweg	Flood plain outside compound channel obtained from DEM and EDM survey data Extent: varies, min: 200m; upstream max: 1 km, risk areas; downstream
Number of Cross-section data	108	213	499
Cross-section interval length	Varies Min: 3m Max: 70 m	20 m	20 m
Total stations (Sta, Elv - points) per section	18 - 23	124 - 138	Min: 100 Max : 199
Number of Nodes	31, 026	106, 904	79, 215
Number of Triangles	61, 380	212, 678	158, 417

a. Silibin   b. Birch Garden

c. Buntong   d. Kuala Pari

Figure 4: The streets, buildings, river, drains, river channel and hydraulic structures of the study reach represented as break lines

3. Results and Discussion

The results of present study show that, the geometry data extracted automatically from ITIN can be used with SFlood model. However, modeller must provide enough physical measurements to describe the geometry and hydraulics of the river reach at the initial ITIN construction stage. Hence, enough field data to be provided in order to construct a correct mathematical and geographical representation of the physical entity that being modelled.
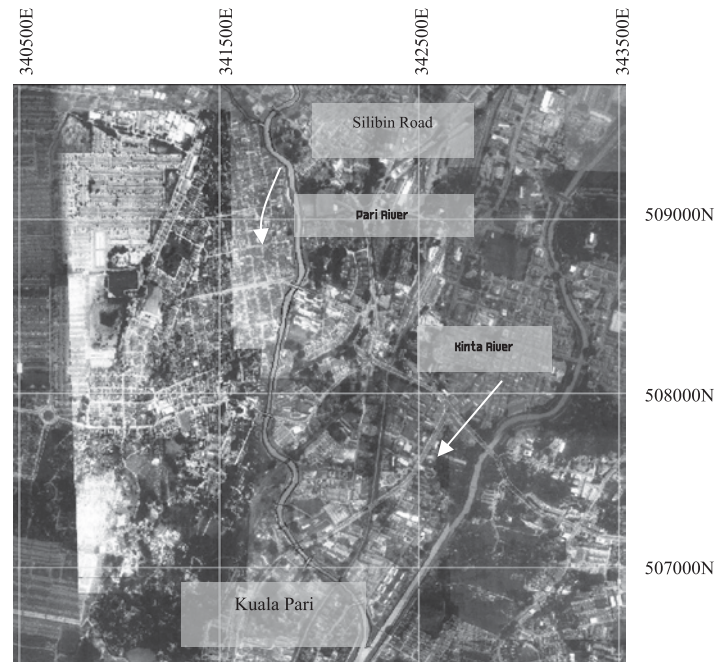
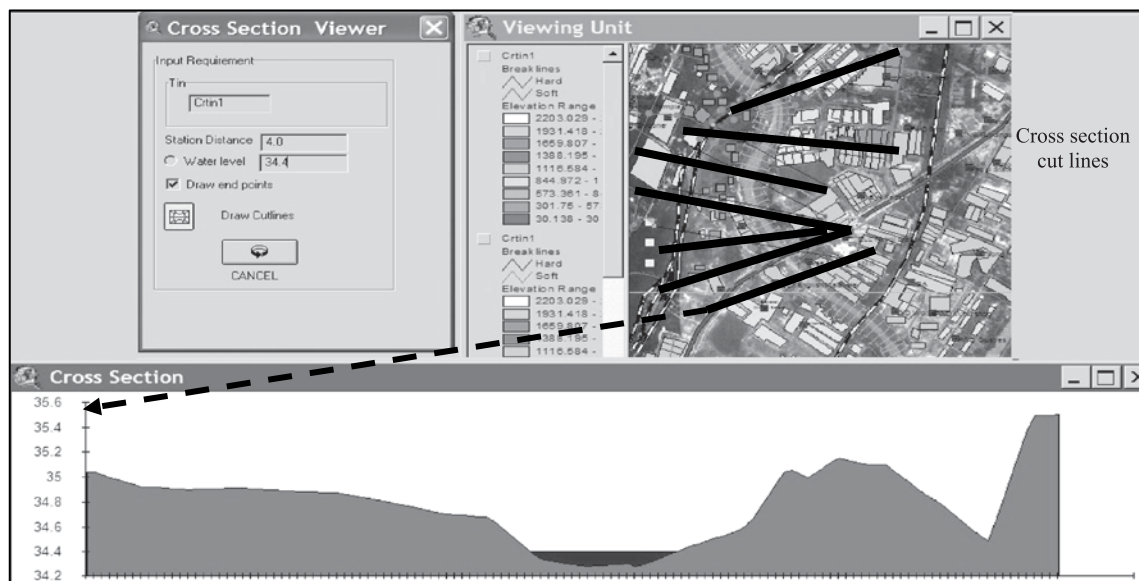Figure 5: Combined aerial photographs of the study area

Figure 6: Visualizing of the cross section based on Cross Section Extractor Tool

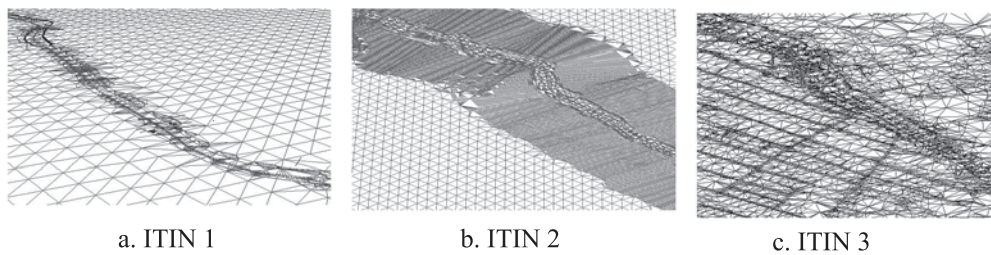a. ITIN 1　　　　　　b. ITIN 2　　　　　　c. ITIN 3

Figure 7: ITIN created with various level of spatial resolution
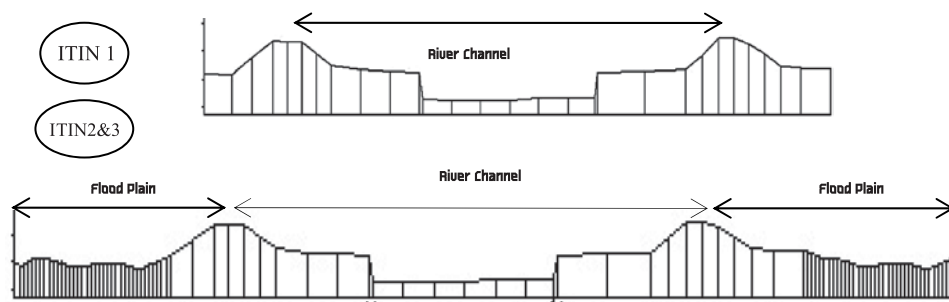
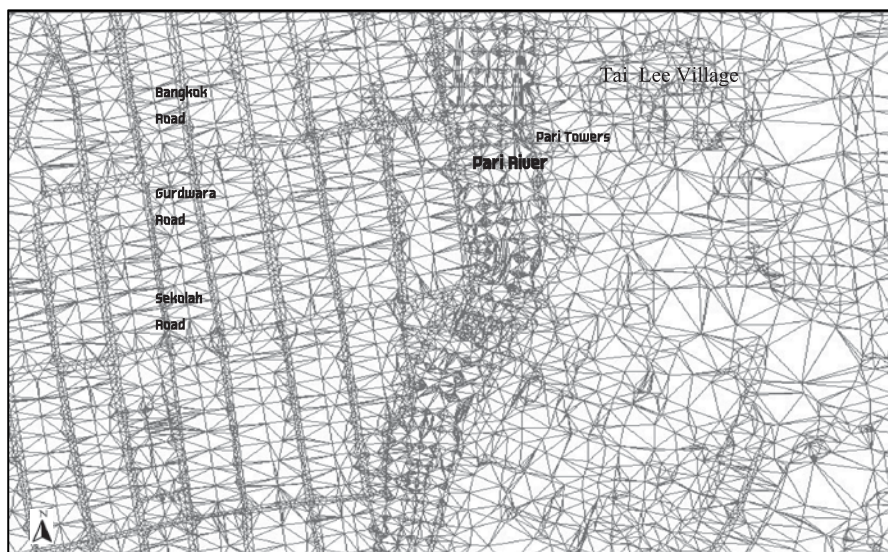Figure 8: Graphic representation of the cross-section for ITIN construction

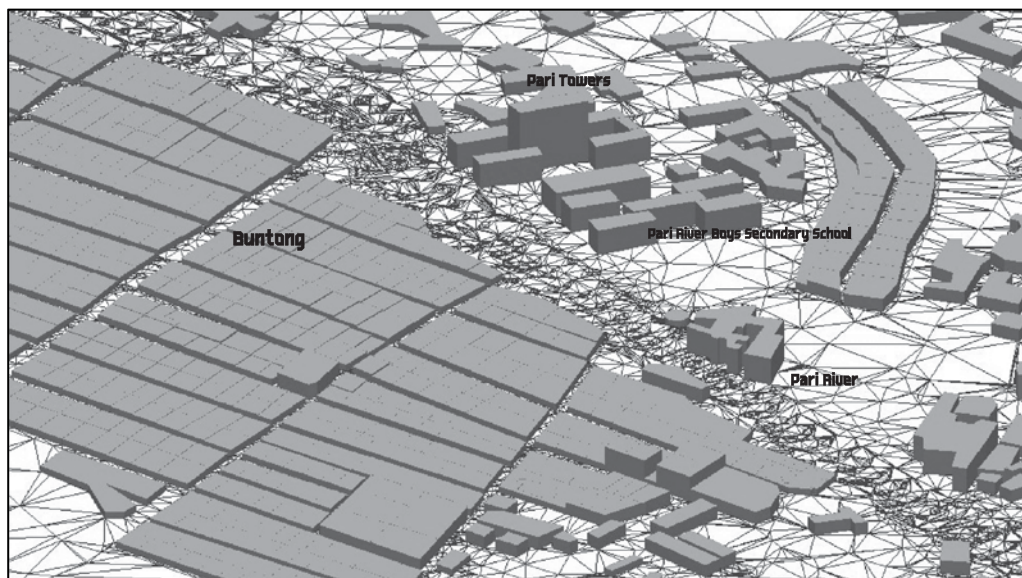Figure 9: Sample mesh of Integrated TIN (ITIN) for study area

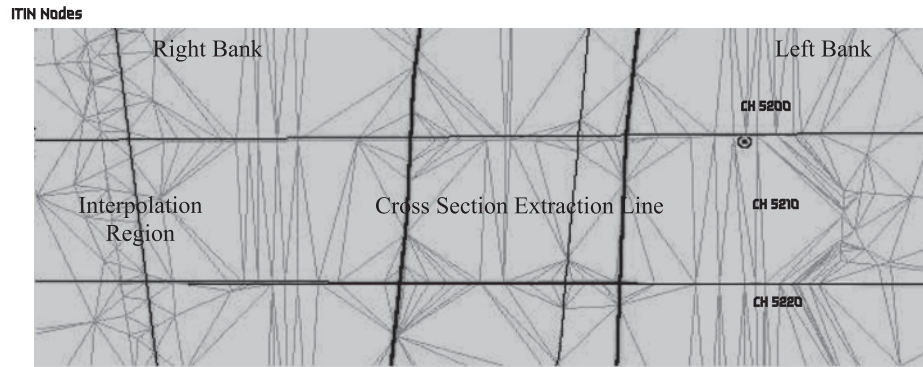Figure 10: Sample 3D Mesh of Integrated TIN (ITIN) for study area

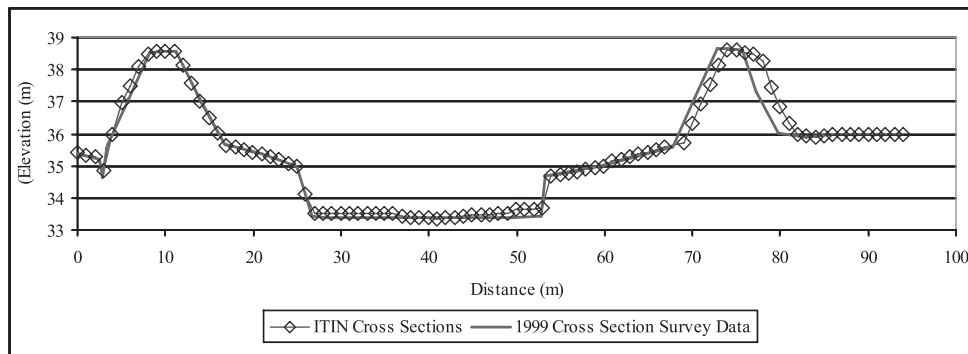Figure 11: Cross section extracted from ITIN mesh

Figure 12: Surveyed and ITIN extracted cross section comparison at the actual location - Chainage 5200
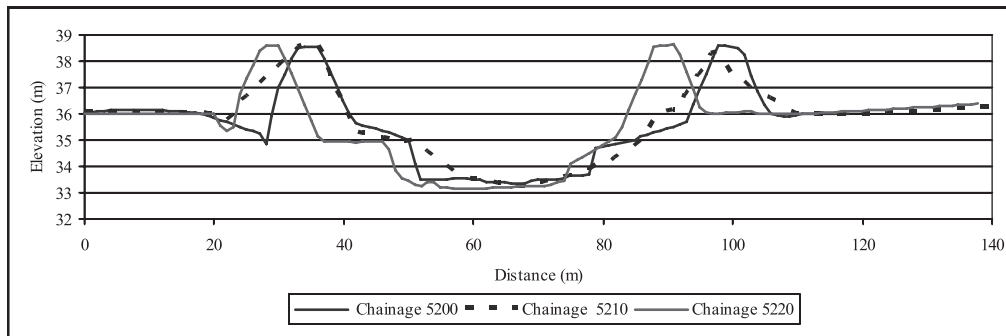

Figure 13: Comparison of the surveyed and extracted cross section from ITIN (Chainage 5210)

Beside this, enough computational cross sections must be provided to ensure that model output is insensitive to the distance between sections. The extracted cross section from ITIN agrees perfectly with the orientation of the surveyed cross section if the cut lines are placed accurately along the surveyed point location in the ITIN (Figure 11 and Figure 12). The dots in Figure 11 show the surveyed elevation points (reduce and invert level) which were integrated in an ITIN. Random cross section extraction in the interpolated region may yield cross section geometries that are not similar to the adjacent sections. Figure 13 shows that, the random extraction of Chainage 5210 does not accurately represent the design bed condition of Pari

River which has a rectangular shape. This causes significant loss to conveyance area of the cross section. Thus, the tendency of the extracted section filled with sediment is very high when the SFlood model was simulated. A very high resolution ITIN can be created by duplicating more cross section values between surveyed sections. However, this method increases the number of nodes in the ITIN, takes longer time to process and visualize the surface and has a high tendency of the interpolation sub routine to crash while processing the data. Thus a computer with very high processing speed and storage capacity is needed to successfully extract the geometry data from a high resolution ITIN.

6. Conclusions

This research gives engineers a simple yet practical GIS toolbox to create a comprehensive ITIN and automatically extract geometric data to be fed into SFlood Hydraulic Model. However, the success of any geometrical data extraction process for hydraulic modelling is very much depending on the resolution of a source ITIN. A high resolution integrated triangular irregular network mesh as represented in ITIN3 in the present study proven to give better results and drastically reduces the human input for making a detailed yet accurate terrain representation. It also provides the modeller the ability to easily design spatial layouts incorporating man-made structures such as streets, buildings and drains as well natural features of the terrains. The geometrical flexibility of the ITIN model allows to setting up of a mesh that represent many complexities of the Pari catchment area, such as sharp building corners, roads, drains inverts and etc. the area. The method of using existing HEC series hydraulic model output files as ITIN source data is only recommended to be used if the high resolution ITIN is not readily available to provide hydraulic inputs for the SFlood model.

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