The Impact of Satellite Digital Elevation Models in Hydraulic Modelling of Water Distribution Network in Addis Ababa, Ethiopia

Yalemzewd Abere Mulu Sisay Demeku Derib (Ph.D.)
Addis Ababa Science and Technology University, College of Architecture and Civil Engineering, Department of Water Supply and Sanitary Engineering

ABSTRACT

Digital elevation models (DEMs) generated from different satellite sources are being used for many engineering projects. Among those engineering projects, DEMs are now being used for water distribution network modeling as input data sources in Ethiopia. Due to its free availability with different resolutions, DEMs are considered as a very cost-effective way of gathering input data for the design and modeling purposes, particularly in water sectors. However concrete studies about the accuracy of DEMs that it might possibly produce are not conducted so far in Ethiopia. In this regard, this study was conducted to quantify and evaluate the impacts of available satellite DEM resolutions in hydraulic modeling of the water distribution network (WDN).Hydraulic modeling of WDN was performed for steady state and extended period simulations for the 12.5X12.5m, 30X30m, Google Earth (GE) and 90X90m DEM resolutions by using WaterGEMSv8i software. The modeling outputs of the software were portrayed that the existence of significant variations in water pressure for the evaluated DEMs.

Keywords: RMSE, MAPE, Field Survey, DEM, Modelling, WaterGEMSV8i
DOI: 10.7176/CER/11-12-03
Publication date: December 31st 2019

1. INTRODUCTION

Digital elevation models (DEMs) can be produced from a vast variety of manner and a large diversity of data sources such as digitized using topographical map (Li, et al., 2010; Kang, et al., 2008; Narender, et al., 2006), discipline measurements the use of a complete station or Global Positioning System (GPS) (Li, et al., 2010; Jacobsen, 2003), the use of overlap of satellite imagery or aerial photograph (Li, et al., 2010; Srivastava, et two al., 2007; Nadeem, et al., 2006; Jacobsen, 2003), the usage of SAR imagery and the usage of LiDAR factor cloud (Li, et al., 2010; Jacobsen, 2003). Each of these strategies will produce digital elevation models facts with one-of-a-kind accuracy (Li, et al., 2010). A DEM is a 3D projection of the Earth that can be labeled into two groups: digital terrain models (DTMs), which are free of trees, buildings, and all types of objects, and digital surface models (DSMs), which mirror the Earth's surface, including all man-made and natural objects (Martha, et al., 2010).

DEMs are vital records sources for various functions that require surface top data (Amans, et al., 2013). DEMs are used as elevation data sources in a number of geospatial research and applications, such as topography, geomorphology, and plant cowl research, tsunami assessments, city studies, archeology, water resources, and glacier observations (Erasmi, et al., 2014; Pope, et al., 2007). Among them, the water distribution community is one phase of engineering applications which required DEM for its hydraulic modelings

In hydraulic models of water distribution network, well-known hydraulic equations are solved to compute principal hydraulic parameters; such as flow rate, velocity, and water pressure, at numerous points for the described WDN and the acquired results are displayed in tabular and graphical varieties to be evaluated by way of the users (Romano and Kaplan, 2012). Water distribution modeling is the most up-to-date technology in the route of enhancement in water provide engineering. In the current day, modeling, is a precarious section of designing and working water distribution systems that are capable of serving communities reliably, efficiently, and safely (Walski et al, 2003). To successfully utilize the skills of water distribution gadget simulation software program and interpret the consequences produced, the engineer or modeler has to recognize the mathematical standards involved (Walski et al. 2003).

A water distribution network has to be modeled in such a way that it can provide the desired volume of water to the customers at enough pressure. The design consists of specifying the sizes of exclusive aspects of the distribution network and checking the adequacy of this network (Mays 2000). Significant effort has been positioned in growing tactics to solve for optimal designs of water distribution systems. The hydraulic modeling outputs of water distribution network can be affected via the use of uncertain input data's. Though there are many input data uncertainties, input information uncertainties due to the use of satellite information for water distribution network modeling is one of the centers of attention of this study.

Therefore, in this study, the freely available satellite DEMs of 90x90m from ASTER, 30X30m from SRTM, and the latest resolution of 12.5x12.5m from ALOS-PALSAR and Google Earth were downloaded from USGS sites. Consequently, the downloaded DEMS were used for hydraulic analysis of water distribution network by using WaterGEMSV8i software.

2. MATERIALS AND METHODS

The research was conducted in Addis Ababa, at Koye Feche area. Koye Feche is located in the southeast direction of Addis Ababa, the capital city of Ethiopia at a geographic coordinate of 8^{0} 54’11” North and 38^{0} 49’60” east. It is found about 20km far from the center of Addis Ababa.

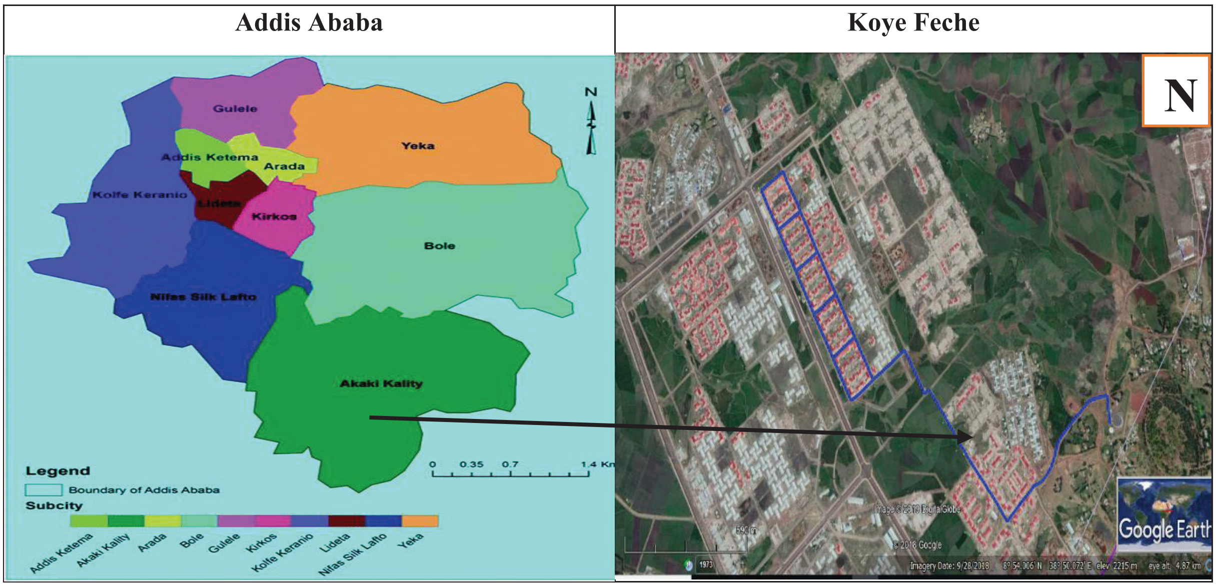


Figure 2.1: Location map of the study area ***(Source: Google Earth&Google Map)***

2.1 Selection processes of the study area

The selection technique of this find out about place was once well-thought-out notable factors which have been viewed to obtain the objective of this study based totally on formerly performed sorts of literature. Studies, which had been associated with this lookup was taken as the baseline for the determination processes. Since the consequences of earlier accomplished studies have proven that there was once a substantial end result distinction in distinct topographical conditions, the sample study area determination tactics need to incorporate distinct topographical conditions. Moreover, in order to conduct all spherical or acceptable studies, the chosen sample study area ought to include the most determinant factors and have to be representative. The key determinant factors as identified by way of formerly carried out studies are elevation, cloud effects of the satellite images (blurred and clear satellite images) and obstructions like; forests, high rise buildings, etc. The selected area contains different terrains conditions observed in between 0-75m elevation differences.

In water distribution network modeling, reservoir site selection is based on head differences between reservoir sites and consumption points. For sustaining allowable pressure standards, which is 15-70 m, an elevation difference of 75m was to be adopted by considering head losses as well, which is fine to meet the objectives of this study. Hence, the selected elevation difference is capable of quantifying the impact of using satellite data’s for water distribution network modeling. The elevation profile of the study area is indicated in figure 2.2.

Figure 2.2: Google Earth elevation profiles of the study area

2.2 Sample sizing and techniques

Samples need to be representative in order to powerfully characterize the whole data sets. Since in this study it used to be aimed to take a look at and quantify the effects of Satellite-based DEMs in hydraulic modeling of WDN, a representative number of samples from hilly as well as flat areas were taken. Figure 2.3 suggests the three dimensional (3D) skeleton of WDN layout in GE each in hilly and flat areas that are from the provider reservoir point up to the consumers.

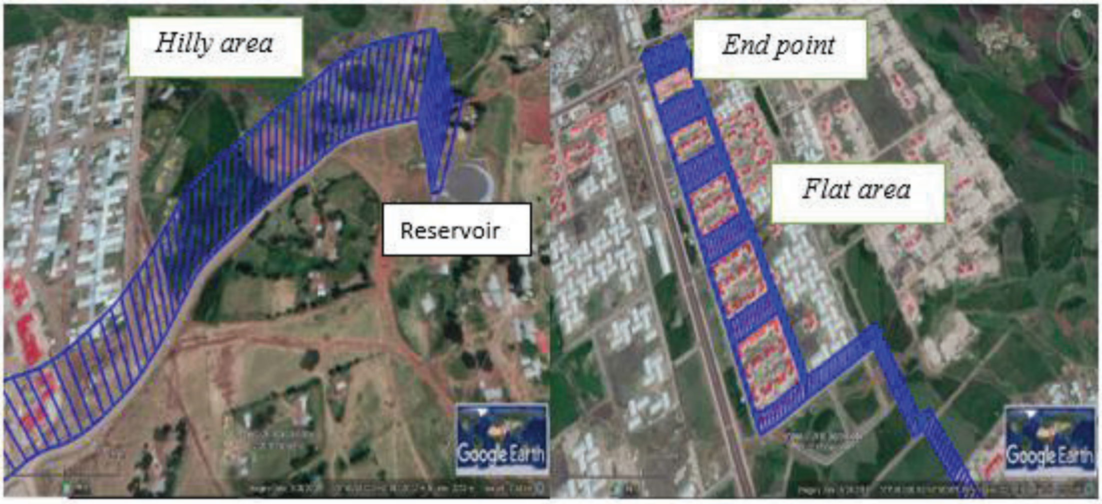


Figure 2.3: 3D view of Google Earth layout of WDN at the hilly area (left) and flat area (right)

2.3 Satellite data

Satellite data from DEMs and GE were used as an input data source for the modeling processes of WDN. As input data's are the building blocks in many engineering projects, an accurate collection and gathering of information from them were conducted seriously. Satellite input data's of having latitude, longitude, and elevations information's were collected from USGS downloading sites as a digital elevation model format. However, the latitude and longitude information's in the case of GE was collected via following different steps see figure 2.4. DEMs of different resolutions were collected as indicated in table 2.1.

Table 2.1: Collection processes of freely available DEMs in Ethiopia Case scenario

DEMs	**DEM Type**	**Sources**
12.5x12.5m	ALOS-PALSAR	ALASKA https://vertex.daac.asf.alaska.edu/
30x30m	SRTM	USGS
90x90m	ASTER	USGS

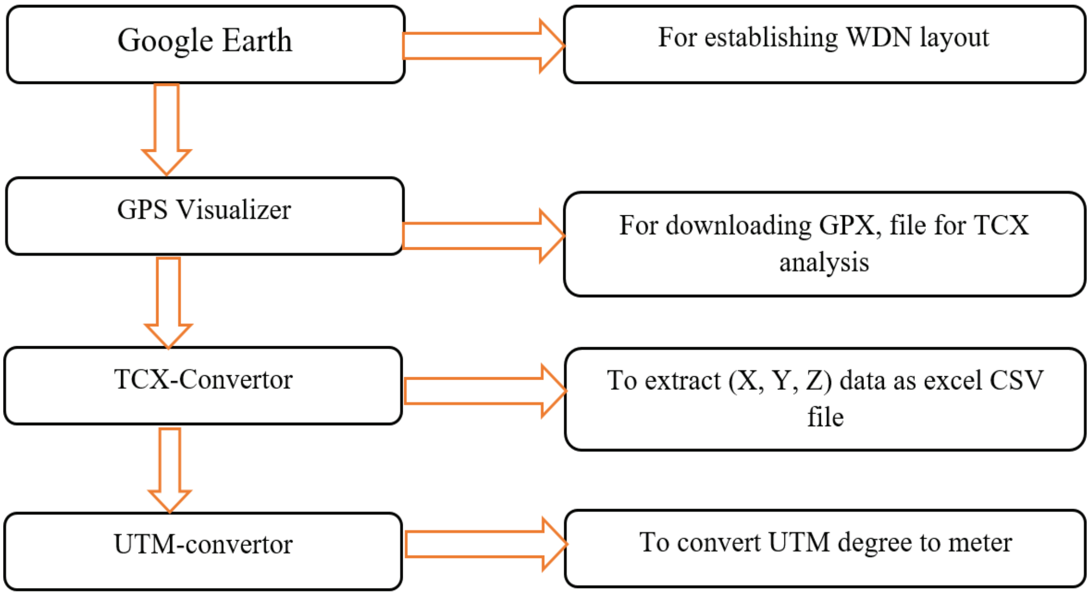


Figure 2.4: Overview of XYZ data extraction processes in Google Earth

2.4 Field survey data

Since the goal of this study was stood to take a look at and quantify the influences of the use of satellite input data's for the hydraulic modeling of WDN, the field survey information collection strategies is a crucial section of this study. Then, a surveying instrument of having a ±2cm degree of accuracy was once used for measurement purposes. The instrument was a real-time kinematic differential global positioning system (RTK-DGPS), model, SOKKIA SCH250. RTK-DGPS is a satellite navigation approach used to enhance the precision of position data derived from a satellite-based positioning system.

Figure 2.5: RTK-DGPS adjustment at the base station (left) and the adjusted base station (Receiver) (right)

Figure 2.6: Taking the first measurement at reservoir location (left), and taking data record with data controller/recorder (right)

Once fixed at a certain base station, this surveying instrument has had a tendency to measure coordinates of points up to 6km radius. The degree of accuracy it might also preserve used to be extraordinarily very excessive as in contrast to a total station and theodolite surveying. While performing RTK-DGPS surveying; first, a base station was once installed over an open region as shown in figure 2.5, to reduce and keep away from the obstruction outcomes it might show up due to the presence of high-rise buildings, trees and other satellite interrupting buildings found in the study area. Second, an appropriate instrument setup and adjustment was carried out as shown in figure 2.5, for making certain that the radio connection of base station RTK-DGPS was once excellent related through Bluetooth with the other RTK-DGPS (Data-Rover) that was used movably for the measurement processes in conjunction with the data recorder/controller shown in figure 2.4. Third, the coordinates of points in the study area were recorded with data recorder/controller starting from the hilly areas up to the flat areas of the study figure 2.5. Eventually, the recorded coordinate data's in RTK-DGPS (i.e from Data-Controller) were transferred from data recorder via a memory card to the laptop computer as a comma-separated value (CSV) file format.

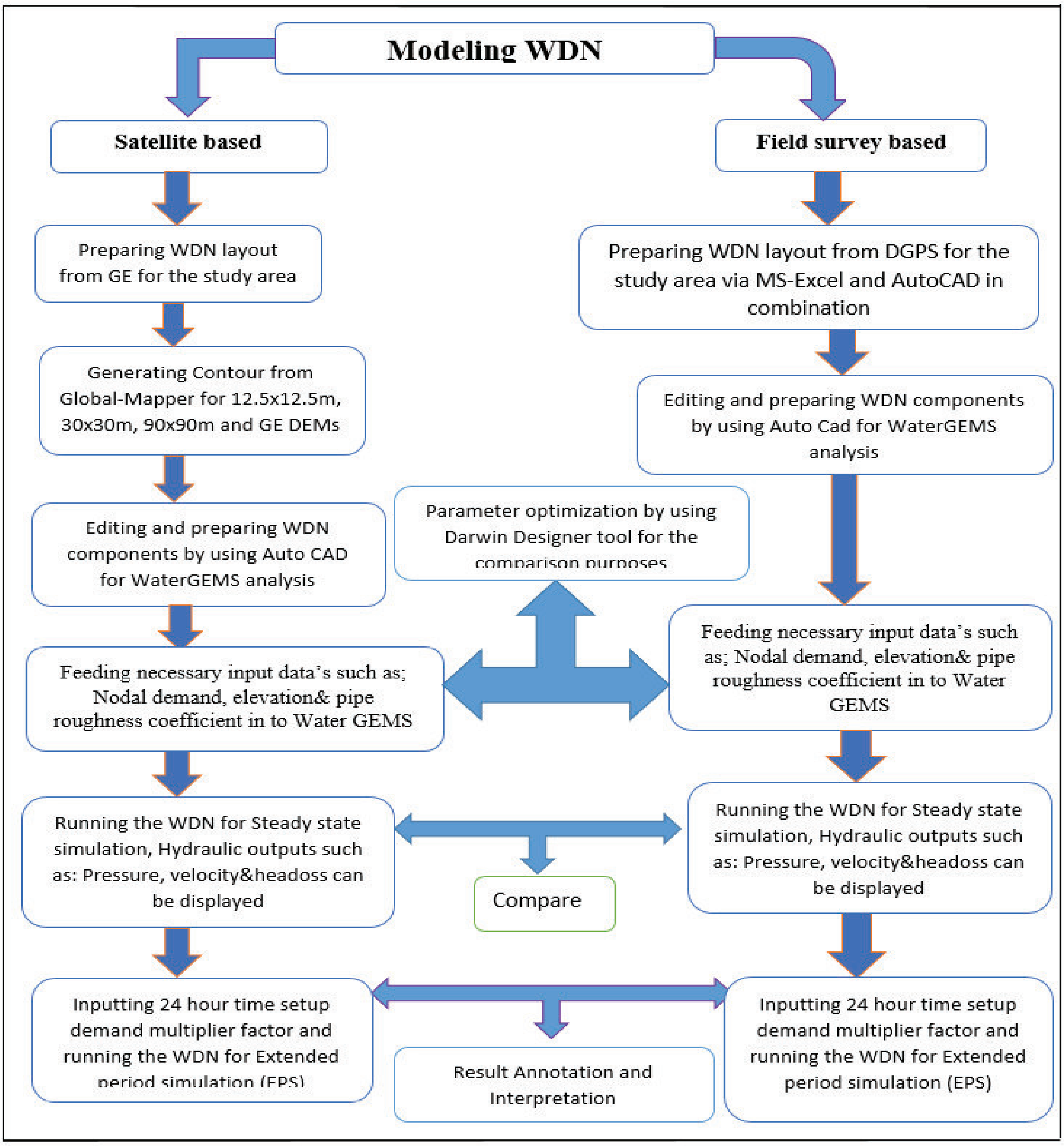


Figure 2.7: Flow charts for the followed overall modeling processes of WDN

2.5 Statistical analysis

In order to examine and quantify the hydraulic modeling outputs of WDN, universally renowned and accepted statistical parameters were used. The mean absolute deviation (MAD), root mean squared error (RMSE) and mean absolute percentage error (MAPE) was entirely applied for the error quantification purposes. Their respective formulas for the mentioned statistical tools are presented as follows.

$$\mathrm{MAD} = \frac{\sum_{t=1}^{n}|\mathrm{At-Ft}|}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{t=1}^{n}(\mathrm{At-Ft})^2}{n}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

$$\mathrm{MAPE} = \frac{\sum_{t=1}^{n}\left|\frac{\mathrm{At-Ft}}{\mathrm{At}}\right|}{n} * 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

Where, MAD = Mean absolute deviation
RMSE = Rot mean squared error
MAPE = Mean absolute percentage error
A_t = Actual data at observation t

F_t = forecast data at observation t
n = Number of observations

3. RESULTS AND DISCUSSIONS

3.1 Hydraulic modeling

Hydraulic modeling in WDN majorly comprises of, modelings of hydraulic parameters such as; pressure, flow velocity, and headloss gradient within the allowable limits and standards for both steady state and extended period simulations. The accuracy of the outputs of hydraulic modeling depends on the accuracy of the provided input data by the modeler for the modeling software. Since many design assumptions and input data preparation works can be performed by the modeler, the certainty of the modeling output is highly dependent on the experience of the modeler.

Most research papers conducted in the hydraulic performances of WDN areas had brought as the major sources of input data error was an improper use of Hazen Williams's pipe roughness coefficient (C-value) and they also used an iterative c-value for their model calibration and validation purposes. However, they were not noticed that the major input data error was inaccurate use of coordinate and elevation data's behind Hazen Williams's c-value that was later verified by this study.

Coordinate and elevation input data for WDN modelings in Ethiopia is obtained from different digital elevation models. For the better optimizations of the hydraulic parameters in the WDN modeling, a modeler should have to realize and identify the levels of accuracy that the digital elevation models provide. Hence in this study, the impacts of using satellite input data's generated from different digital elevation models for the hydraulic modelings of WDN were examined and quantified by using a hydraulic modeling software WaterGEMSv8i for both steady state and extended period simulations for different DEM scenarios.

3.2 Steady state comparisons of pressure in different DEM scenarios

The pressure is a determinate parameter in the WDNs. Insufficient and excess pressure in WDNs are frequent problems. Hence, an optimized and accurate estimation of pressure in the WDN is a critical task for a modeler. DEMs are the main input data for modeling pressure by using hydraulic simulation software's. The information extracted from DEMs is coordinates and elevations that ultimately was used as an input data for pressure junctions for further WaterGEMS analysis. Coordinate and elevation information's are the driving factor for the hydraulic computations of pressure by using Bernoulli's equation. Therefore, pressure in the water distribution network is mainly affected by input data uncertainty generated by using different DEMs. The simulated pressure for a steady-state scenario for different DEMs are shown in figure 3.1.

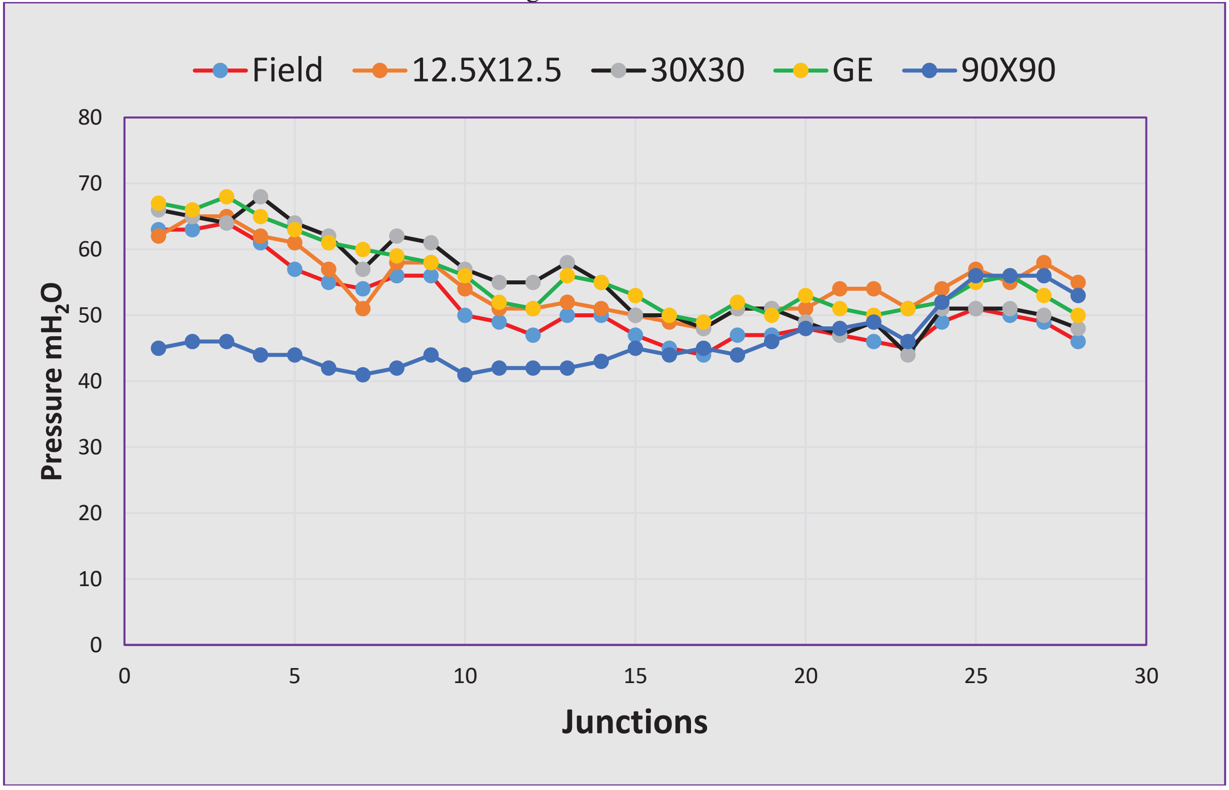


Figure 3.1: Steady-state simulated pressure for different DEM scenarios

In the above figure 3.1, the simulated pressure by using 90X90m DEM resolution was explicitly dropped as compared to the other DEM resolutions. This portrays that using 90X90m DEM resolution for modeling water distribution network might result in a significant pressure loss. Whereas, the variations in between 12.5X12.5m, 30X30m, and GE DEM resolutions were found to be nearly similar. Figure 3.2 has clearly shown the statistical values computed for different DEMs for the simulated pressure.

3.3 Extended period comparisons of pressure in different DEM scenarios

During the extended period simulation, pressure in the WDN can vary with the established time setups commonly 24-hours. Here in this analysis, two basic scenarios are important. One is a maximum consumption hour scenario and the other one is the minimum consumption hour scenario. These scenarios are being used in water distribution system experts and modelers. The main target of these two scenarios is to check whether residual pressure in the water distribution system at maximum and minimum consumption hours are maintained or not. TAHAl (2015), recommended [20 – 80 mH_20] of pressure. Figure 3.2 and 3.3 illustrates the simulated pressure in the extended period scenario for different DEMs at maximum and minimum consumption hours respectively.

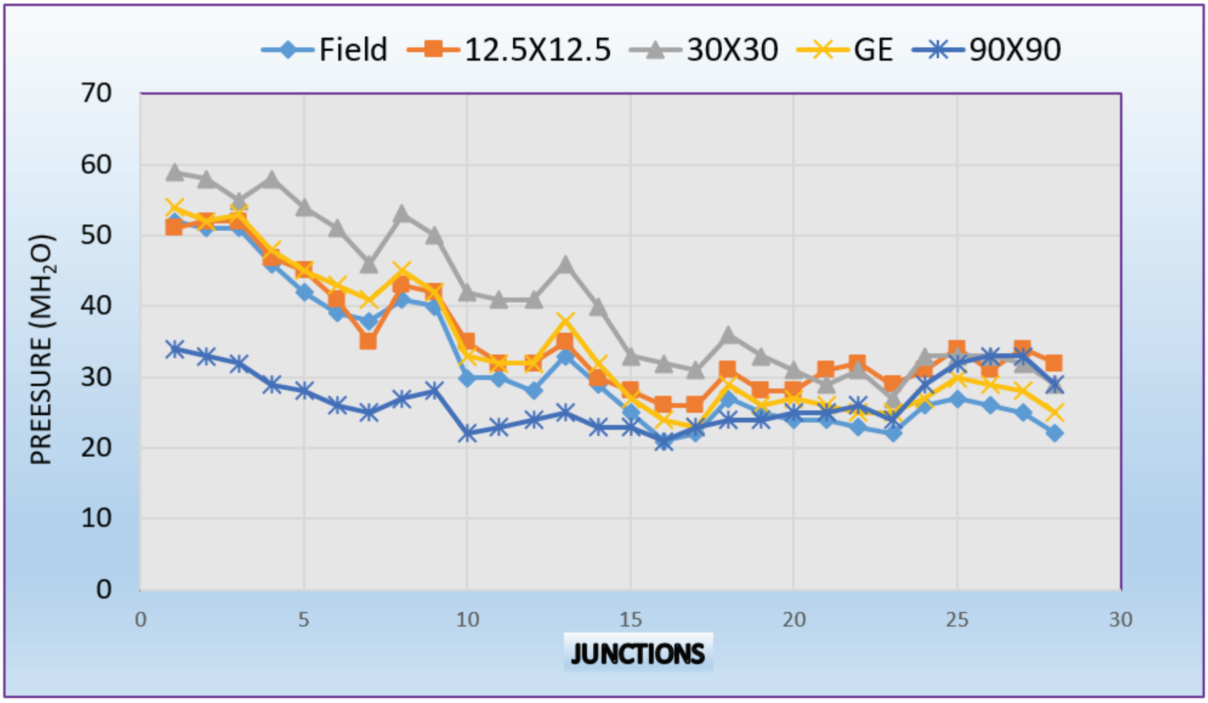


Figure 3.2: Pressure at maximum consumption hour for different DEM scenarios

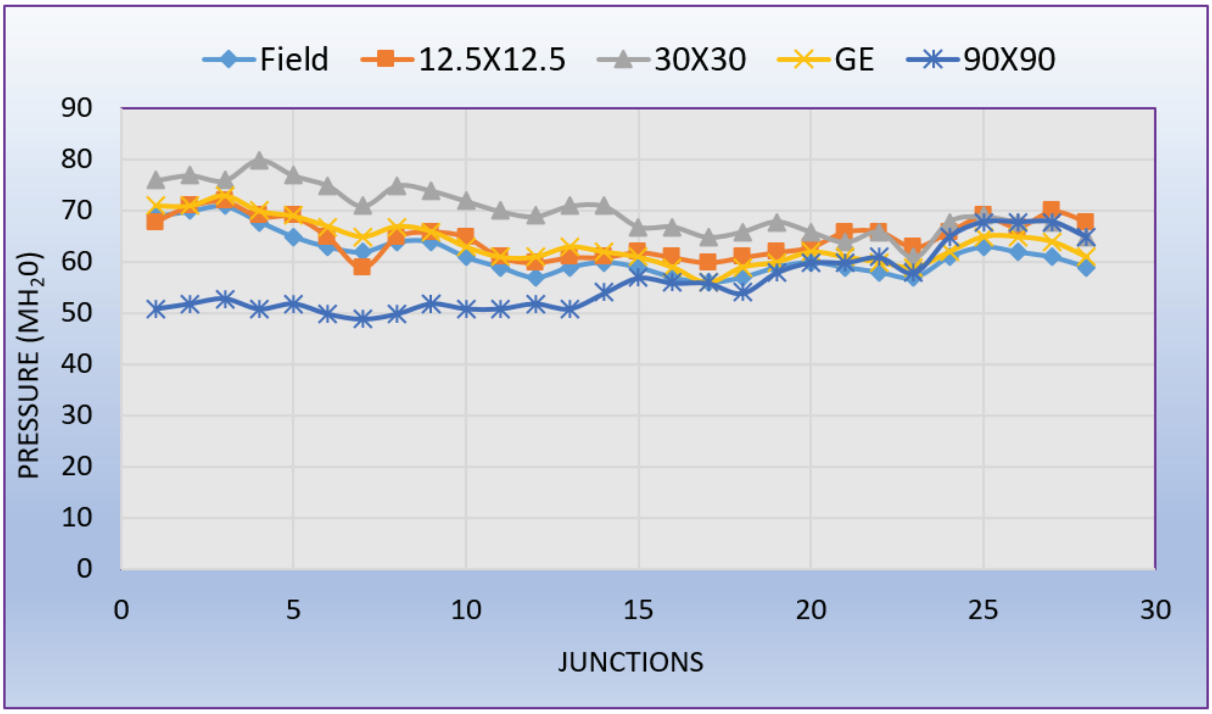


Figure 3.3: Pressure at minimum consumption hour for different DEM scenarios

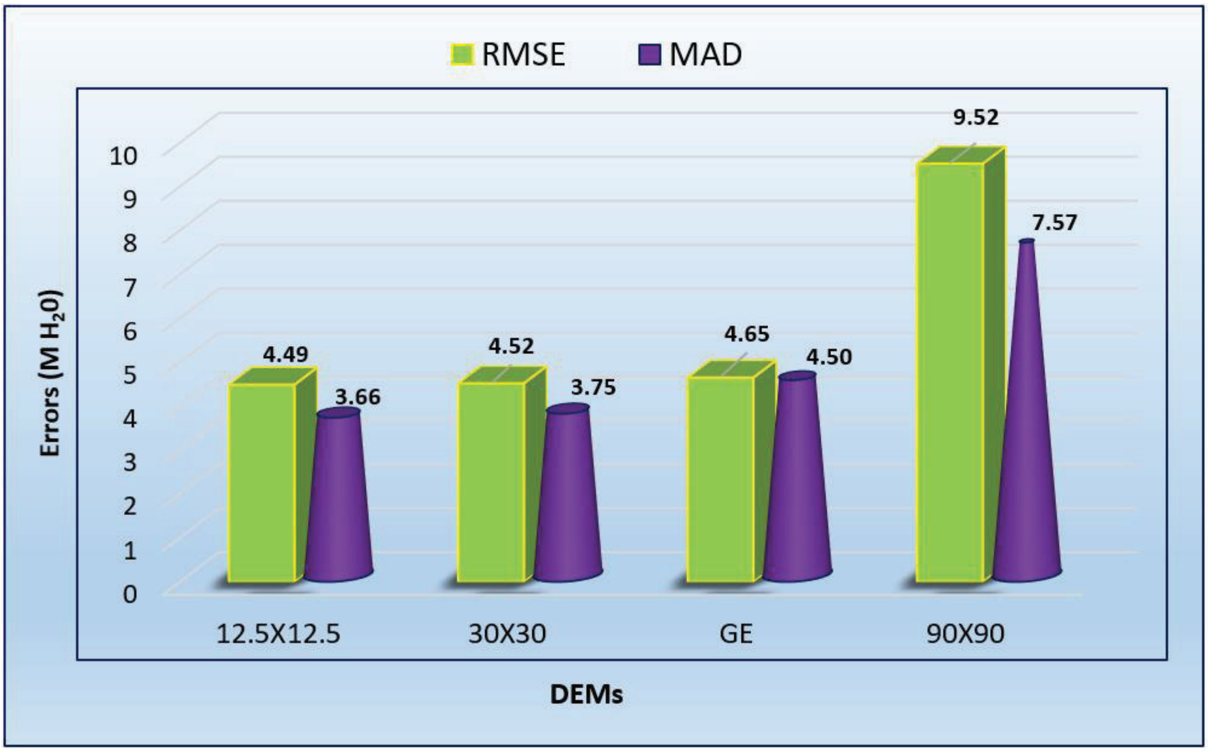


Figure 3.4: Root mean squared error and mean absolute deviations for different DEM scenarios for the simulated steady-state pressure

The RMSE value for 12.5X12.5m, 30X30m, GE and 90X90m DEMs were found to be 4.49, 4.52, 4.65 and 9.52 m also, a MAD value of 3.66, 3.75, 4.5 and 7.57 m respectively. The computed RMSE and MAD value depict that insignificant differences in terms of pressure in between 12.5X12.5m, 30X30m, and GE DEMs. However, significant differences in pressure for 90X90m DEM was observed. A 3 mH_20 drop in pressure can result in loss of one story pressure head for multi-story buildings. In general, a drop in water pressure ranging from [4.49 – 9.52] mH_20 in RMSE for the compared DEM scenarios was observed. This error range can cause to the emerging of inadequate and excess pressure in the water distribution network.

In line with the RMSE and MAD statistics, MAPE statistics was applied for the determination and quantifications of error in terms of percentiles or percentages. Then the result showed that WDN modeling on the basis of 12.5X12.5m, 30X30m, GE and 90X90m DEMs can provide a MAPE of 7.29, 7.35, 8.93 and 13.82% loss in pressure respectively. Figure 3.5 depicts the percentage pressure loss while using different DEM scenarios for modeling WDN.

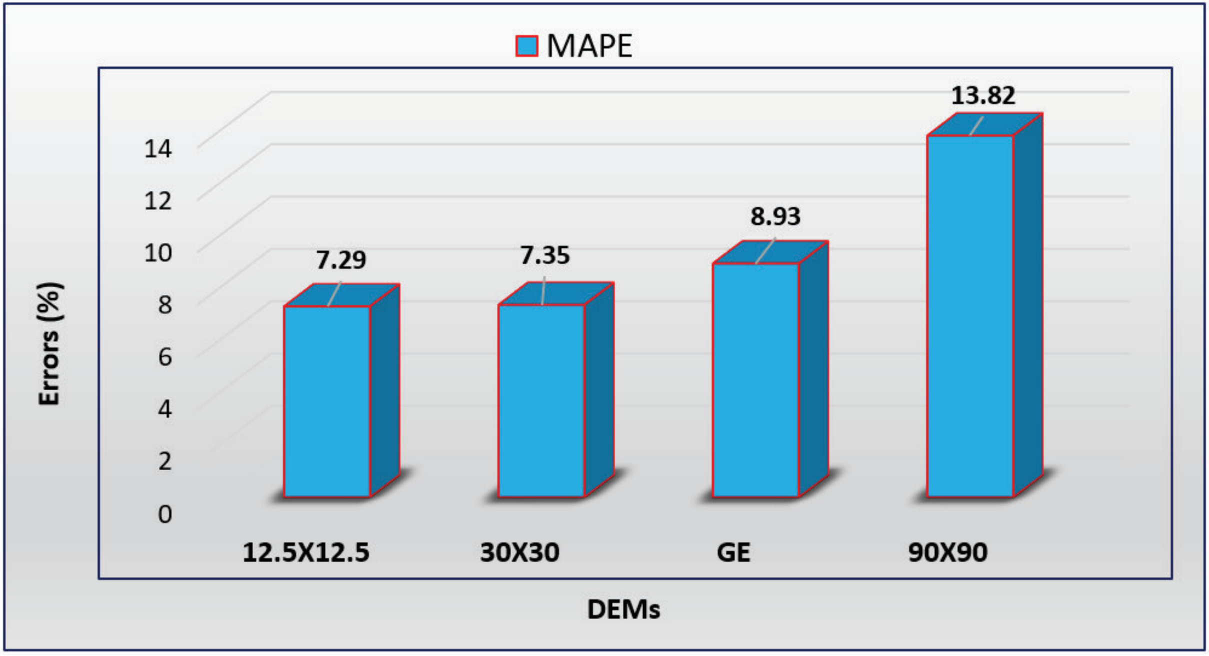


Figure 3.5: Mean absolute percentage error for different DEM scenarios for the simulated steady-state pressure

3.4 Velocity and Headlosss

According to the continuity equation, velocity and headloss in a water distribution system are mainly a function of pipe diameter. As pipe diameter increases, velocity decreases and headloss also decreases and vice versa. Therefore for the hydraulic analysis of WDN in different DEM scenarios, pipe diameter was kept similar for the purposes of comparison. Hence it was not possible to observe the variations in velocity and headloss in WDN.

4. CONCLUSIONS

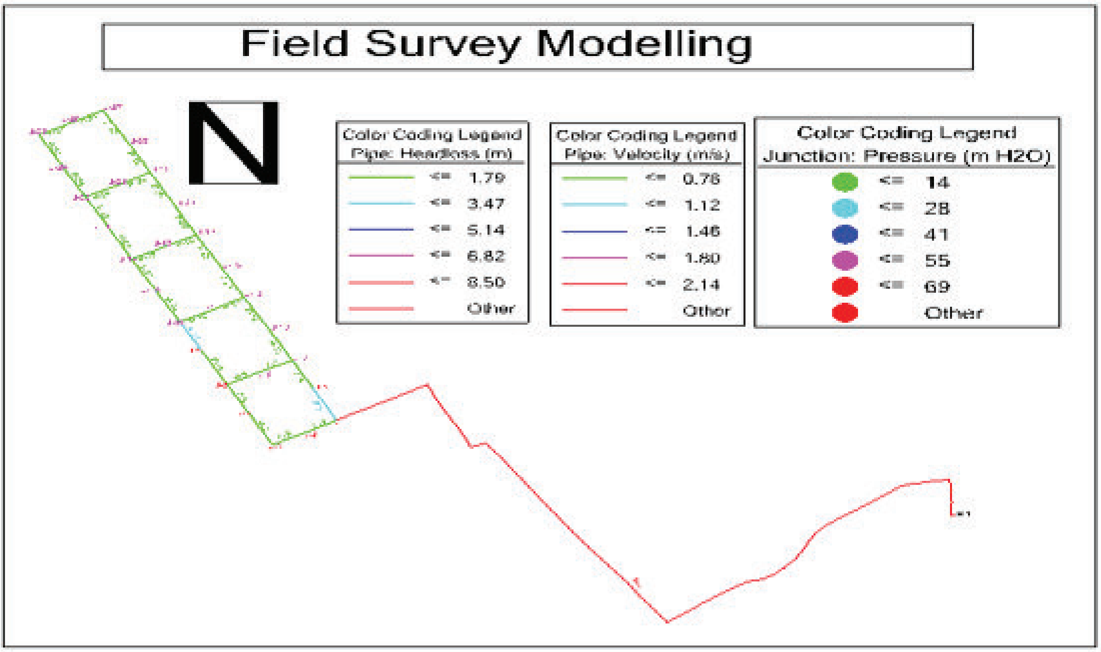
This study was addressed the aforementioned objective the impact of satellite base DEMs in the hydraulic modellings of WDN. Different approaches were adopted and applied to quantify the study outputs. Water distribution networks were modeled for hydraulic parameters for the compared DEM scenarios by using WaterGEMSv8. The modeling outputs of the software were portrayed as significant variations in water pressure. However, the hydraulic outputs of velocity and headloss were kept constant since they are a function of pipe diameter. Among the compared DEMs, the modeling outputs of 12.5x12.5 resolutions were provided a better result than the rest do have. Moreover, the 30x30 and GE DEMs were found better than 90X90 DEM resolutions.

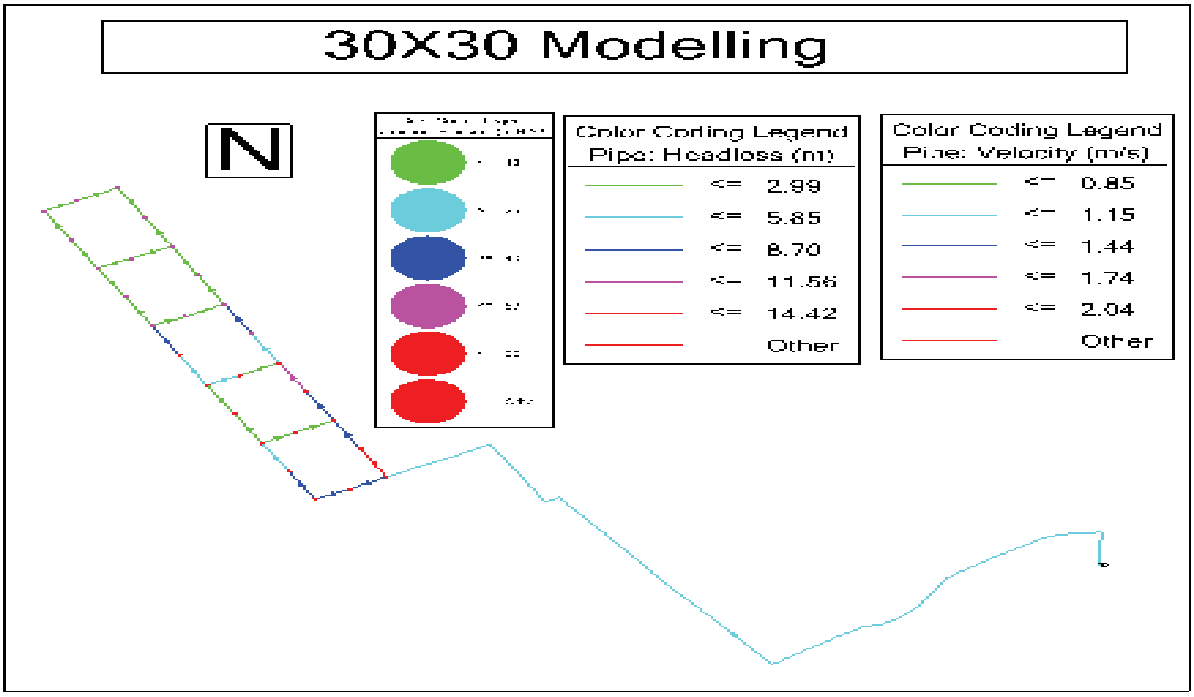
5. REFERENCES

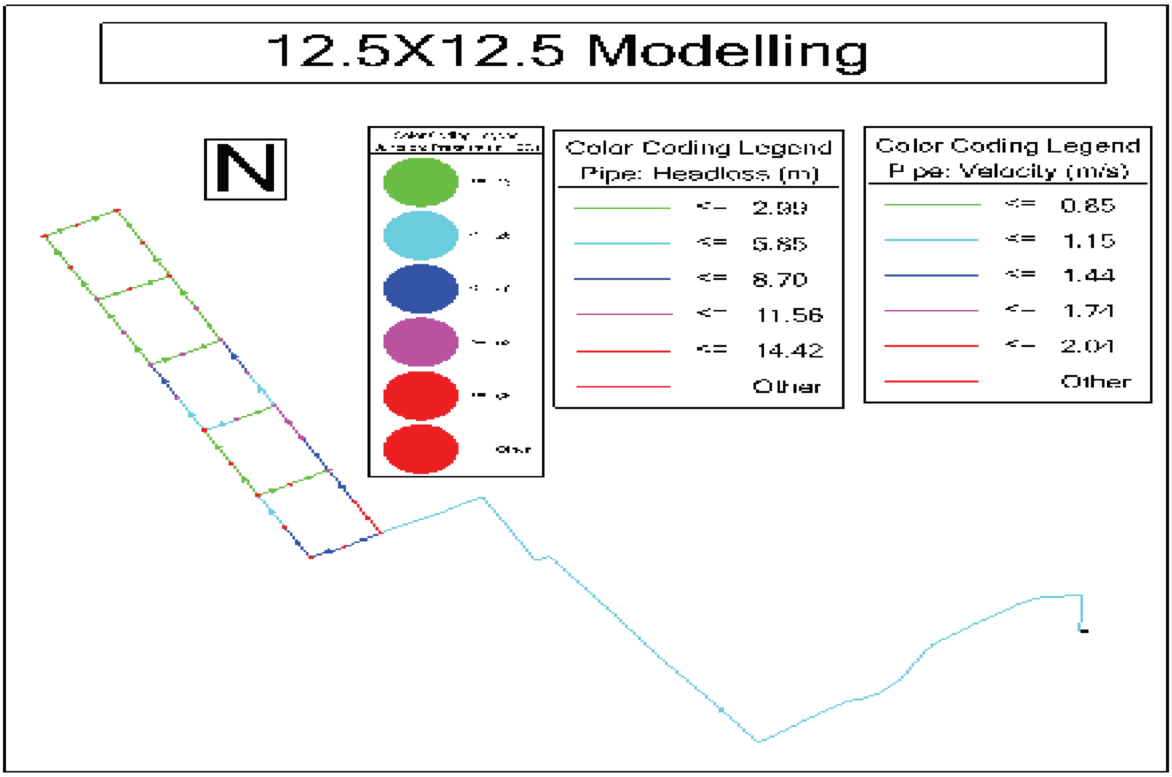
1. Amans, O.C.; Beiping, W.; Yevenyo, Z.Y. Assessing Vertical Accuracy of SRTM Ver 4.1 and ASTER GDEMVer 2 Using Differential GPS Measurements: Case Study in Ondo State Nigeria.Int. J. Sci. Eng. Res. 2013, 4,523–531.
2. Erasmi, S.; Rosenbauer, R.; Buchbach, R.; Busche, T.; Rutishauser, S. Evaluating the quality and accuracy of Tan DEM-X digital elevation models at archaeological sites in the Cilician Plain, Turkey. Remote Sens.2014, 69475–9493.
3. Jacobsen, K. 2003. DEM Generation from Satellite Data. European Association of Remote Sensing Laboratories Ghent, pp. 273-276.
4. Kang, J. M., Yoon, H. C. and Park, J. K. 2008. Evaluation of the Possibility of Ortho Imagery Production Using SPOT 5 Single Image. XXIst ISPRS Congress Technical Commission IV, 37Part B4, pp. 1279-1282.
5. Li, Zhilin, Zhu, Q.and Gold, C.2010. Digital Terrain Modeling: Principles and Methodology, New York, CRC Press.
6. Martha, T.R.; Kerle, N.; Jetten, V.; van Westen, C.J.; Kumar, K.V. Characterizing spectral, spatial and morphometric properties of landslides for semi-automatic detection using object-oriented methods.Geomorphology2010, 116, 24–36.
7. Mays, L. W. (2000). “Introduction.” Water Distribution System Handbook, Mays, L. W., ed., McGraw Hill.

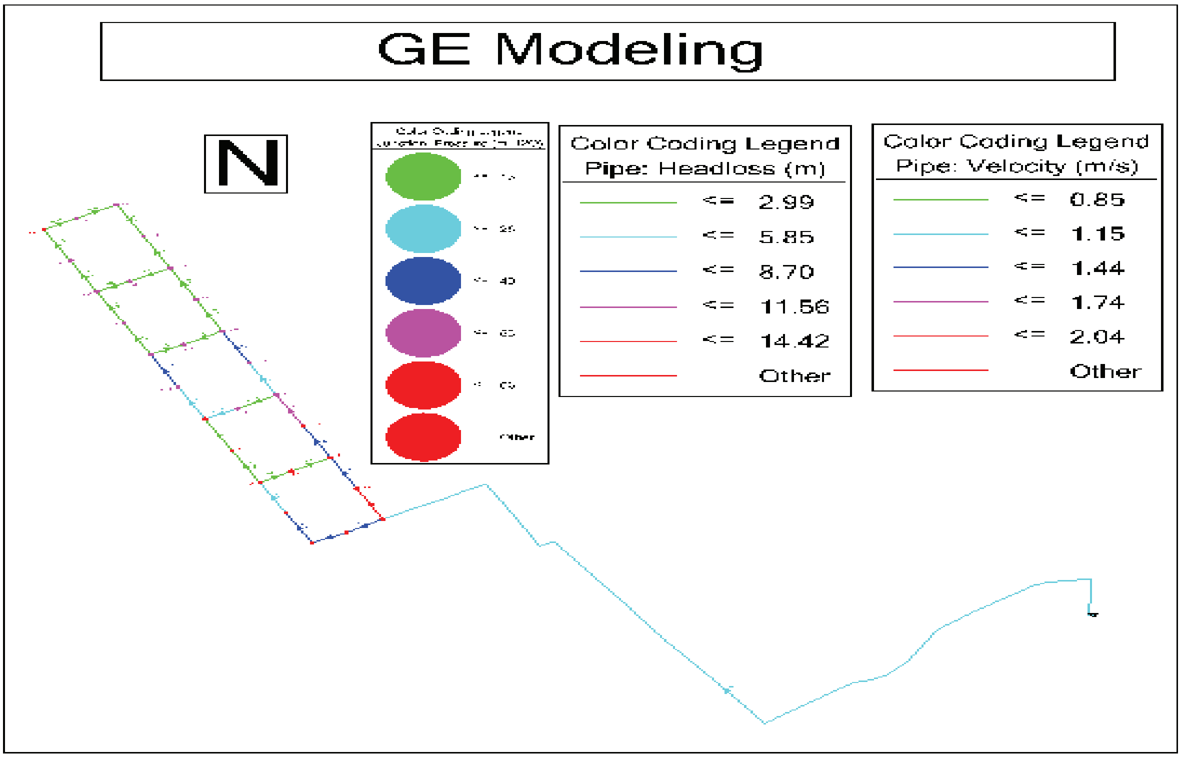
8. Nadeem, A., Ritesh, A., et al., 2006. Validation of Cartosat-1 DEM Using Differential GPS Measurements. Symposium of ISPRS Commission IV, 36 Part 4.
9. Narender, B., Rao, B. S., et al., 2006. Validation of C-Band SRTM Demands its Application for Orth rectification. Symposium of ISPRS Commission IV, 36 Part 4.
10. Pope, A.; Murray, T.; Luckman, A. DEM quality assessment for quantification of glacier surface change. Ann. Glaciol.2007, 46, 189–194.
11. Romano M., Z. Kapelan, D.A. Savic, (2012). Automated detection of pipe bursts and other events in water distribution systems, J. Water Resource. Plan. Manage. 140 457–467.
12. TAHAL, Consulting Engineering, (2015). "Addis Ababa Water Supply Project III A (AAWSP-III A)", Volume VII-1.
13. Walski et al., 2003 Walski, T.M., Chase, D.V., Savic, D.A., Grayman, W., Beckwith, W., Koelle, E., 2003. Advanced water distribution modeling and management. Haested Methods, Waterbury, CT.

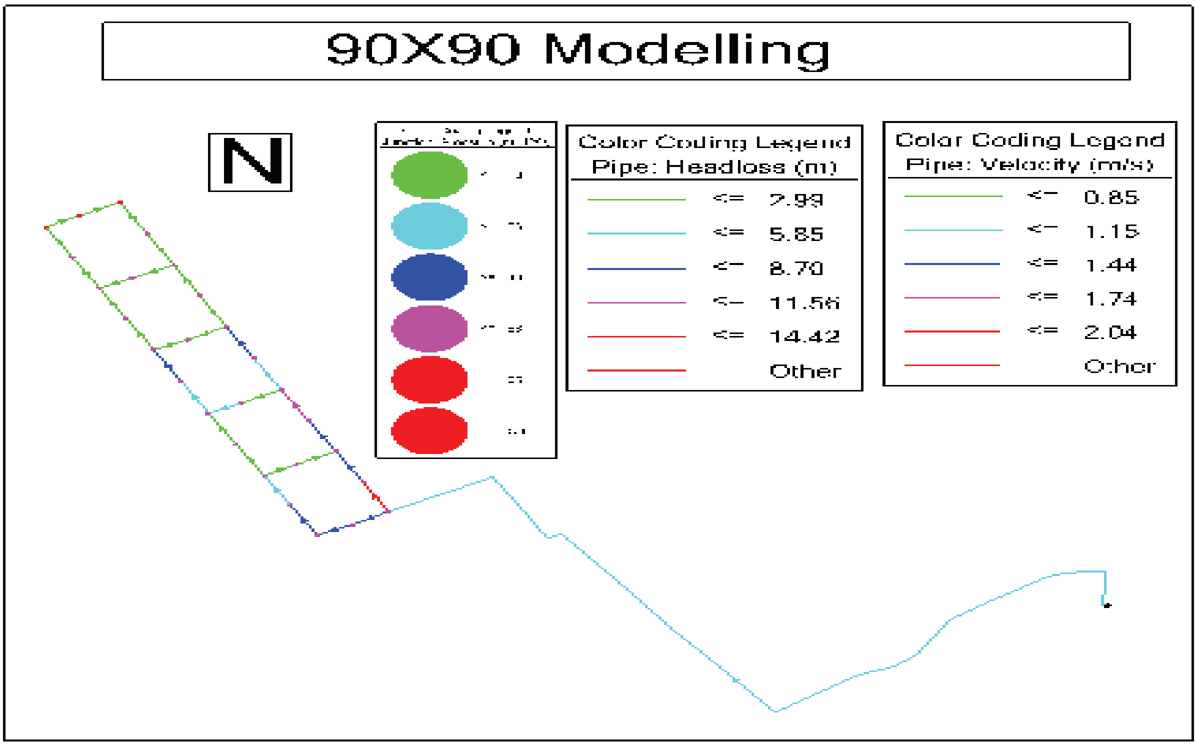
Appendixes on: Hydraulic modelling for different DEM scenarios




30X30 Modelling
N
Color Coding Legend
Pipe: Headloss (m)
<= 2.99
<= 5.85
<= 8.70
<= 11.56
<= 14.42
Other
Color Coding Legend
Pipe: Velocity (m/s)
<= 0.85
<= 1.15
<= 1.44
<= 1.74
<= 2.04
Other


12.5X12.5 Modelling
N
Color Coding Legend
Pipe: Headloss (m)
<= 2.99
<= 5.85
<= 8.70
<= 11.56
<= 14.42
Other
Color Coding Legend
Pipe: Velocity (m/s)
<= 0.85
<= 1.15
<= 1.44
<= 1.74
<= 2.04
Other


GE Modeling
N
Color Coding Legend
Pipe: Headloss (m)
<= 2.99
<= 5.85
<= 8.70
<= 11.56
<= 14.42
Other
Color Coding Legend
Pipe: Velocity (m/s)
<= 0.85
<= 1.15
<= 1.44
<= 1.74
<= 2.04
Other


90X90 Modelling
N
Color Coding Legend
Pipe: Headloss (m)
<= 2.99
<= 5.85
<= 8.70
<= 11.56
<= 14.42
Other
Color Coding Legend
Pipe: Velocity (m/s)
<= 0.85
<= 1.15
<= 1.44
<= 1.74
<= 2.04
Other