Evaluation of Hydraulic Performance of Water Distribution System for Sustainable Management

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Research Article

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Abstract

Understanding water distribution system hydraulic performance is crucial for a water supply system management. A case study was conducted evaluating the hydraulic performance of water distribution system of Tulu Bolo town. The hydraulic model of water distribution network was developed using GIS integrated with WaterGEMS hydraulic model. The implementation of the integrated system verified that water to regulate the pressure and velocity in order to sustain. According to the analysis, about 92.6% of nodes have optimized pressure ranged between 15m to 70m and about 1.27% is under permissible pressure. Model calibration was performed by comparing simulated data with field data, the result of pressure calibration has a linear correlation coefficient of 0.93 and the hydraulic model in WaterGEMS was calibrated and optimized with a field data.

1 Introduction

Water networks are fundamentally geospatial, comprising a set of interconnected hydraulic components, transporting water in the right pressure and flow in the requirements of urban areas and deliver water in the right quality. However, to effectively model these interconnected hydraulic components, a utility must know the geospatial location and the ways it is interconnected both physically and functionally (Do et al., 2017; Herrin et al., 2017). The GIS integrated with WaterGEMS hydraulic model offer analytical solutions for modelling, designing and operational intelligence of water utilities. One of the major challenges of developing countries distribution network modelling is inefficient and improper methods of geospatial database of water distribution networks and its management. Hence, to solve these problems the network was modelled by the use of Geographic information system technology starting with a few files of AutoCAD format, where the plotting of network elements found. The plotting of pipes and other elements were imported and the missing information were completed in ArcMap.

Based on GIS integrated with WaterGEMS hydraulic model, as demonstrated here a set of comprehensive modelling, management, and spatial decision support system analysis system for water supply network in this paper. Hence, initiation of computer technology has generated increased interest in methods that facilitate the realistic modeling of geometric networks as well as manage hydraulic network model data (Sudheer, 2019). Sudheer (2019) in his work evaluates the ever-increasing demand can be fulfilled by designing efficient water distribution networks based on advance computing systems include modern hydraulic modeling and designing softwares.

Shamsi (2004) described three basic methods of developing GIS based modeling application, i.e., interchange, interface and integration as a tool to diagnose the system water productivity and reduces cost. The integration of GIS with the hydraulic model WaterCAD provides opportunities for spatial analysis, a system of record assets, and data management (Alrayess et al., 2017; Eljamassi et al., 2013). The proposed method was evaluated for the hydraulic situation of the water network and the results showed the method to be suitable.

Vairavamoorthy et al., (2004) investigated GIS technology integration with EPANET hydraulic model and applied to spatial decision support system for solving pipe risk mitigation problems of water distribution system. As demonstrated here, the contaminant entrance potential and potential pollution area of water pipes were displayed as thematic map in GIS and the areas resulting in high risk were identified from the GIS maps. Pindiga and Sani, (2015) examined the GIS technology for mapping water distribution network and the task of GIS technology is locating underground pipes and the features installed within water supply. The logical architecture is studied by having the logical position of various features within the water distribution network helps for the proper management, strategic planning and operation managements.

Kruszynski et al. (2020) examined an integrated GIS and the hydraulic model to improve water supply and sanitary networks into one coherent management system, owing to which a holistic assessment of the functioning of the water and sewerage management system in the city is possible. Their work evaluates the integrated system should allow to regulate the hydraulic situation of the network to its value at serviceable range and reduce age of water to the required level.

2 Materials And Methods

2.1 Study area

The research was conducted in Tulu Bolo town, located in south west of Addis Ababa at a distance of 80 km on the Addis Ababa to Jimma road. Tulu Bolo is geographically located at 8°38' 30"N to 8°40' 0"N latitude and 38°12' 30"E to 38°14 0"E longitude and it has an average elevation of 2193 meters above mean sea level. It has 1058mm average annual rainfall and 18℃ average daily temperature.

2.2 Data collection

The input data required for the analysis and simulation of water network; two kinds of data were sourced. The primary data was obtained through direct measurement of node pressure on the field and selected node elevation. Meanwhile, secondary data encompass pipe label, pipe material, pipe length, starting node, stopping node, pipe roughness coefficients are some of the water network input data required for modeling water distribution network. The other input data associated are population data, layout map, cadastral, and pipe network distribution.

Following hydraulic modelling process was adapted in this paper, which was in Fig. 2 to find the solution method for infrastructure through the GIS integrated with a WaterGEMS hydraulic model.

2.3 Building water distribution network Geodatabase

The geodatabase was created by applying the model builder to connect the hydraulic model with geodatabase in WaterGEMS for ArcMap. The hydraulic model was created by importing the water network and the attribute data from the master geodatabase, which was formed in ArcCatalog. The hydraulic model was created by importing the water network and the attribute data from the master geodatabase to WaterGEMS for ArcMap. All data points such as junctions, tanks, and end caps were imported as nodes and distribution network as lines. The hydraulic model components imported were used to directly manage entities through their associate GIS geometry by searching and accessing their attribute and simulation results.

2.4 Sample size and sampling techniques

Water distribution network sampling techniques for model calibration followed the standard methods of water distribution sampling techniques (USEPA, 2005). Therefore, representative, accessible, and operational samples were taken both at higher and lower pressures zones for sampling point. The location of nodes and pipes that formed the sampling frame for the calibration test locations were done by systematic random sampling. Therefore, as per the stipulated criteria for a low to highly detailed network model, the average (6%) of all the junctions were taken as sampling point. Thus, ten sampling points were taken as sampling point. The location of the field pressure measurement points are presented in Fig. 3.

2.5 Demand allocation

Demand allocation is the task performed in a water distribution network modeling for assigning the water demand of the study area. Allocation of calculated base demands to the nodes in the network though GIS integrated with a WaterGEMS hydraulic model is consisting of several methods used in assigning demands were point load data, area load data, and Land use data. The method used in assigning demands through point load data needs detailed household survey inorder to find the exact number of georeferenced billing meters data, nearest node and pipe within a service polgyon. In area load data method the corresponding area is influenced by the node within the given network. From the methods of assigning demands by area load data, the method through proportional distribution by population practically applicaple to most of the study areas where the demands to the nodes in the network are assigned by creating the Thiessen polygons to the corresponding nodes. The last method in assigning demands through land use data methods the demands are calculated by land use and populaton, and assigned to nodes in the network based on landuse classification. As it was known that the methods of point load data and land use data were not capable for unavailability of data like georeferenced billing meter data, nearest node and pipe, land use classification in the study area.

The methods of assigning demands obtained through thiessen polygon followed the method adopted for calculation of nodal demands through proportional distribution by population (Sudheer, 2019). The influence regions shapefile created from the junctions and the point file containing the consumption data were set as a target vector layer and the join vector layer respectively. The geometric ground was set to include all points that are contained within the polygon areas of the voronoi layer and the attribute field must to be set. The GIS integrated with a WaterGEMS hydraulic model approach allocated consumptions of all the uses to the network node by proportional distribution by population. Thiessen polygon is constructed around each node of the pipe network of the distribution system of the city as shown in Fig. 4 with load builder facility.

3 Results And Discussions

3.1 Population projection

Among the different approaches of population forecasting methods, the study analyzed the method which performed well in terms of similarity and/or least deviation from the census population. The results of all the projections plotted against latest census population, and analyzed the approach which performed well in terms of similarity and least deviation from the census population were selected. Accordingly, the geometric increase method was adopted for further water demand calculations, since the geometric increase method performed better population estimation in terms of similarity to or least deviation from the census population.

3.2 Water demand assessment

Water demand estimation was made according to MoWR, (2006) demand categories present in the study area. Hence, the design period populations of Tulu Bolo town were 59720 which have been categorized under category – 3. Based on the category of the town, the mode and levels of service which used for domestic demand estimation was utilized. Non domestic water demand is planned out to be according to MoWR, (2006) percentage of domestic water demand. The water demand is the summation of all consumptions present in the study area and it would determine the capacity needed from the source.

Table 3-1: Estimation water demand up to 2040.

Population in 2019	**Projected number of populations**				
	2020	**2025**	**2030**	**2035**	**2040**
24178	25241	31305	38826	48153	59720
	water demand needs (m^3/day)				
Maximum daily demand	1219.82	1250.67	2628.79	3367.83	4253.72
Peak hour demand	182973	1876.03	3943.19	5051.75	6380.58

3.3 Model calibration and validation

The hydraulic model calibration was made by comparing simulated value with measured values in the field. The pressure was measured in the distribution networks using a portable pressure gauge at public fountain and different end users tap. The results of pressure measured and simulated by GIS integrated with WaterGEMS hydraulic model, as it was observed that RMSE is minimal, and has correlation coefficient of 0.9302, which indicates a significant degree of linear dependence.

In addition, the hydraulic model in WaterGEMS was calibrated in the Darwin calibrator feature and optimized until a great agreement with the field data, as can be observed in Fig. 7.

3.4 Analysis of pressure in the network

The analysis of the pressure distribution is a decisive parameter in water distribution network modeling. As a result of simulations carried out in the existing models, it was found that it is possible to reconstruct the actual working conditions water supply network. The pressures are distributed in the range of 11.004 mH_2O to 70 mH_2O, with few nodes with pressures greater than 70 mH_2O (Fig. 8) at the time of peak hour demand.

The result of simulation run was obtained after model constricted from the input data of existing data a total node of 156 was reported from the study inventory dialog box software. As described in Fig. 8 above, 92.26% of consumption nodes have acceptable pressure limits between (15–70) mH2O.

3.5 Analysis of velocity in the network

The analysis of the speed distribution made on the existing state models of all tested water supply networks showed that most pipes, its value are lower than the recommended. The result of velocity distribution show that up to 59% of the network have low which may causes low water quality due to water stagnation, increase age of water, sediment accumulation and bacteriological growth in a pipe network. This is 116 out of 196 pipes which had a velocity lower than 0.3m/s. A total of 80 pipes out of the 196 links accounting for 41% presented velocity between 0.3m/s to 2m/s, which is recommended range for water distribution network. According to the velocity result at Fig. 9, the velocity percentage between pipes divides into five intervals and

3.6 Developing pressure zone boundaries

The result of the study indicates that, the ArcMap integrated with the WaterGEMS hydraulic model enhanced more detailed elevation contour and pressure contour. The pressure is strongly linked to the topography with a lower ground and the nodes are subjected to higher pressures. The integrated system can generate accurate, smooth contours for any variable including pressure, hydraulic gradient and flow directly on the map with a defined contour interval. The contours are mapped in the interval of 0.5 (Fig. 10) at the time of greatest demand.

4 Conclusions

In conclusion, this study analyzed the possibility to evaluate a GIS based water distribution system modelling. The results, obtained with GIS integrated with WaterGEMS hydraulic model, in terms of hydraulic simulation show that resulting pressure at most junctions and velocities at most pipes were adequate to deliver water to consumption points. Further studies recommended for reinforcing the water network geospatial databases like mapping household water connection and it is relational class between the parcels and water customers.

5 Declarations

Ethical Approval (not applicable**)**

Consent to Participate (not applicable**)**

Consent to Publish (we both the authors of this research will provide full consent for the publication of this manuscript to the journal of water resources management)

Authors Contributions (the first author (Tarekegn Kuma) is the leading researcher whereas the second author (Brook Abate) is the supervisor of the research. Both of the authors have actively participated in preparing and editing the manuscript)

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Competing Interests (as far as we know, no competing interests on this article)

Availability of data and materials (most of the data and materials are included in the manuscript)

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Figures

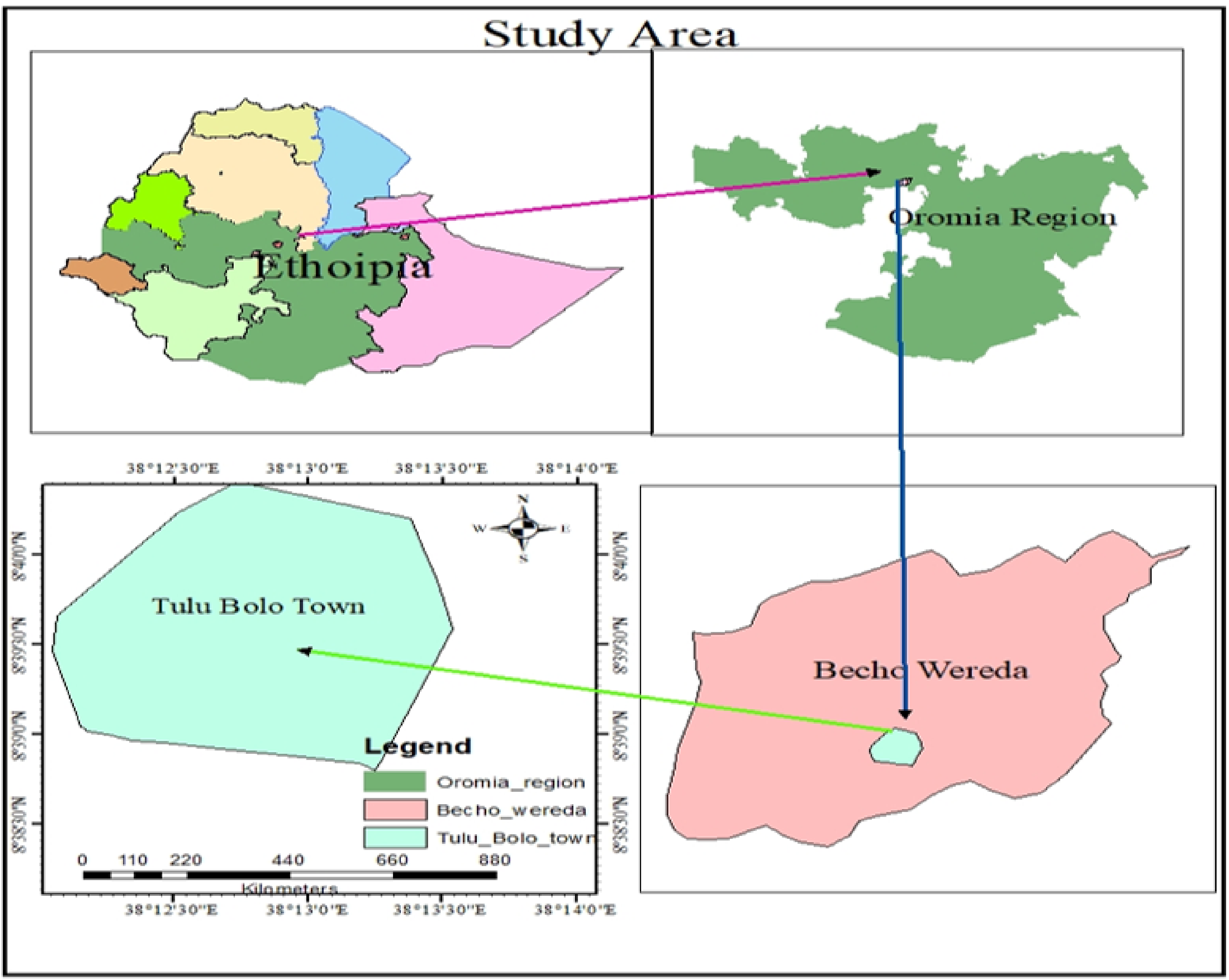

Figure 1

Map of Ethiopia, Oromia, Becho wereda, and Tulu Bolo town

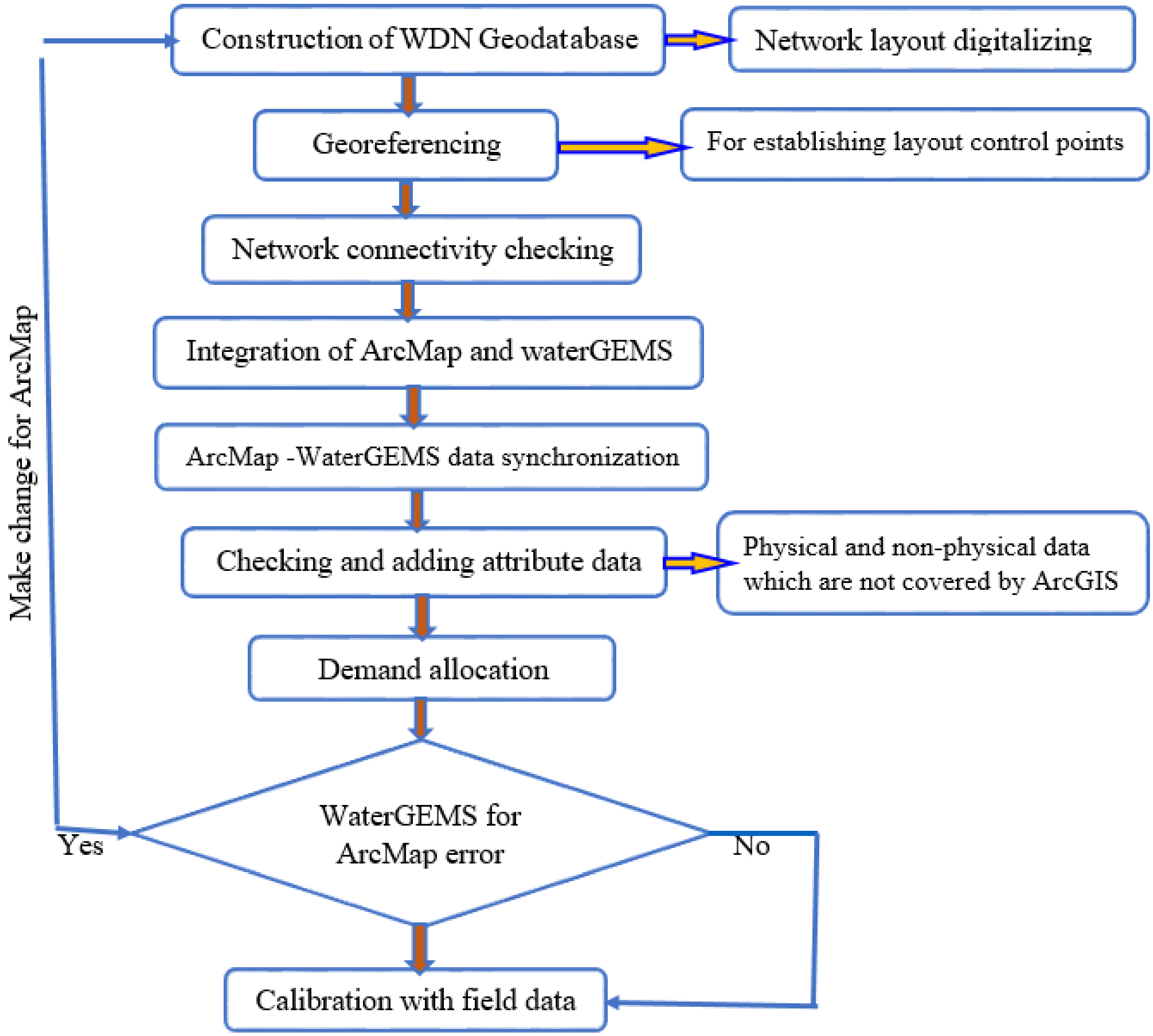

Figure 2

Schematic flowchart for the overall modelling processes of WDN

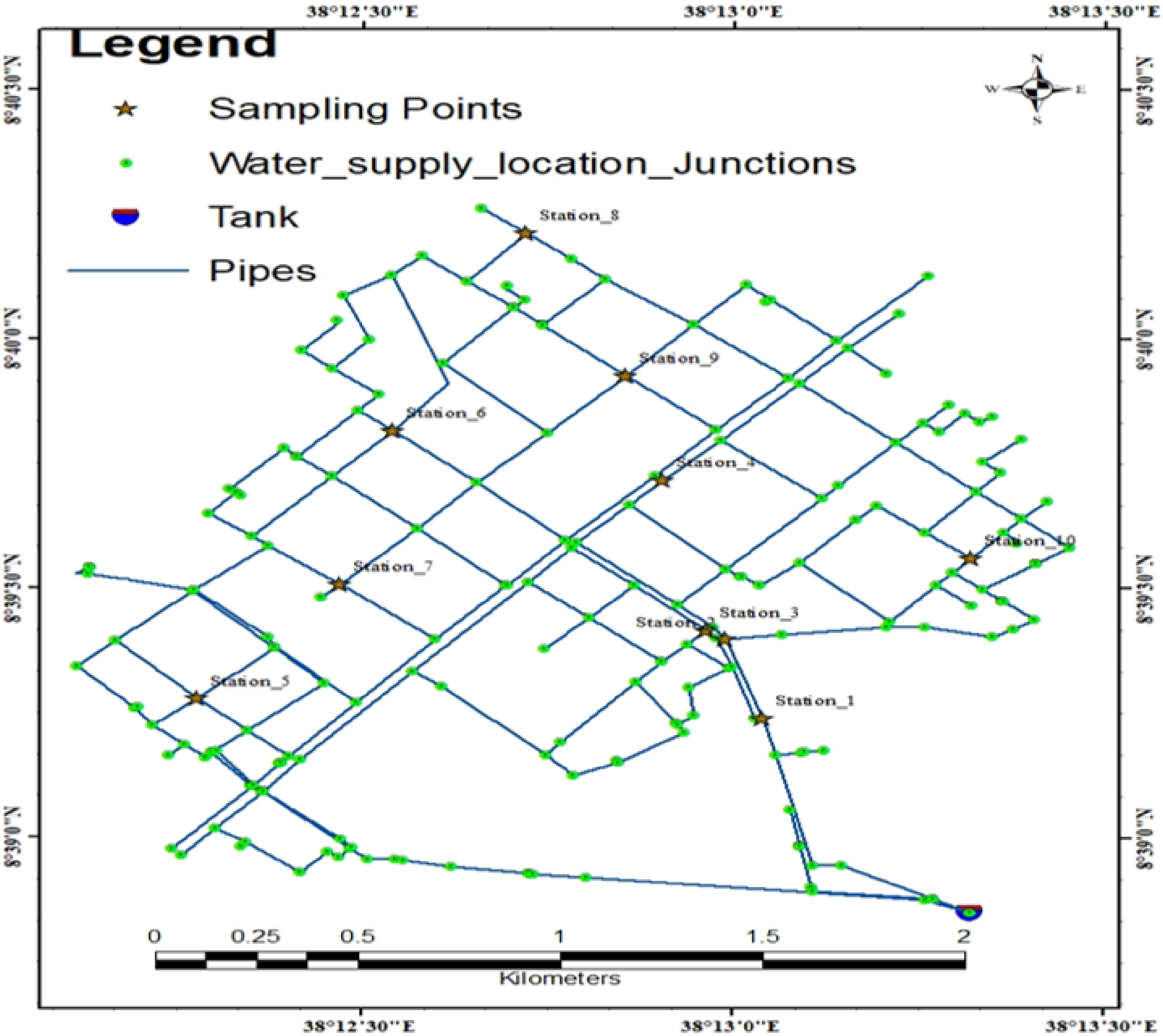

Figure 3

Sampled calibration test locations

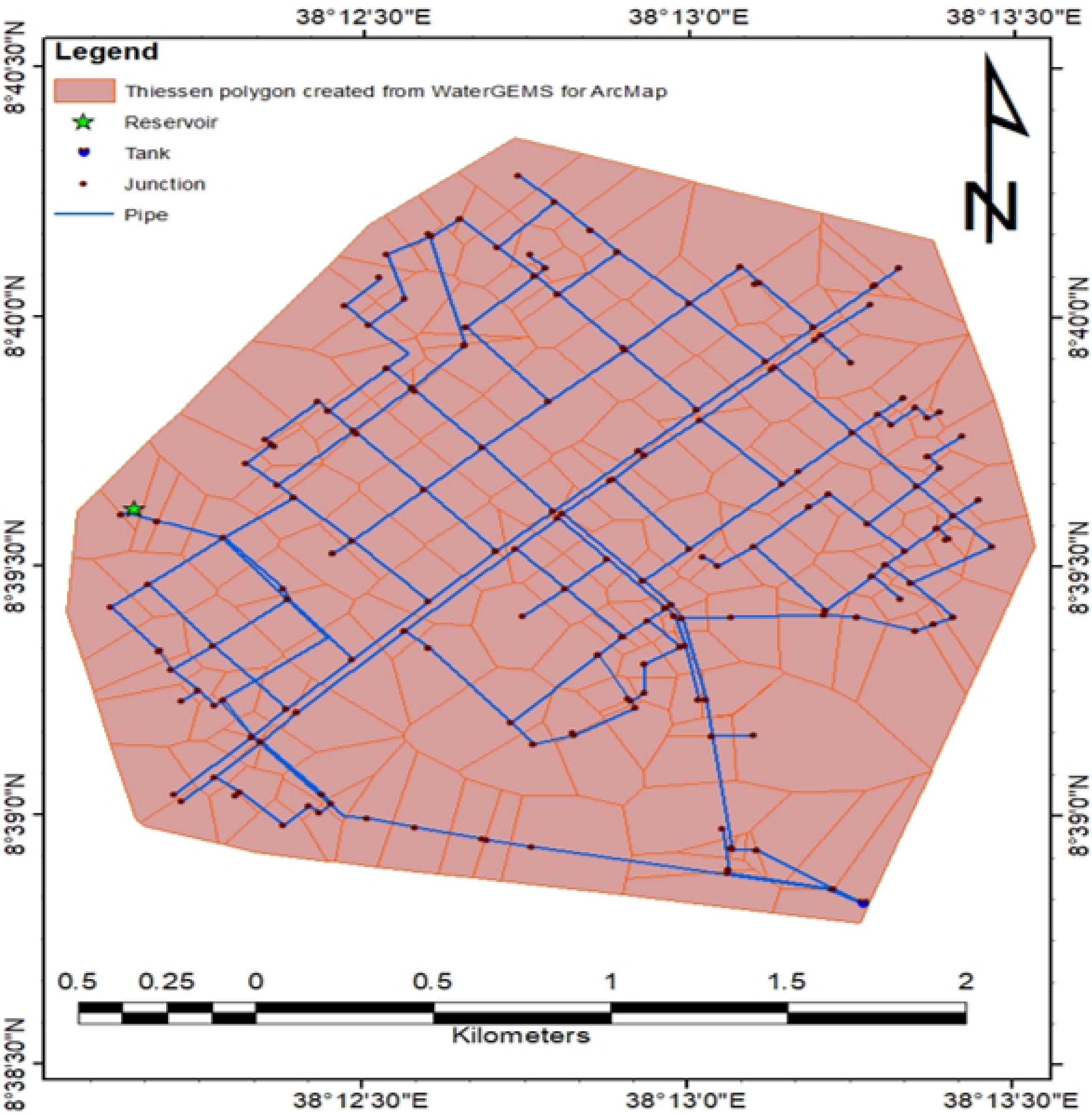

Figure 4

Thiessen polygon map or influence regions for nodes in the network

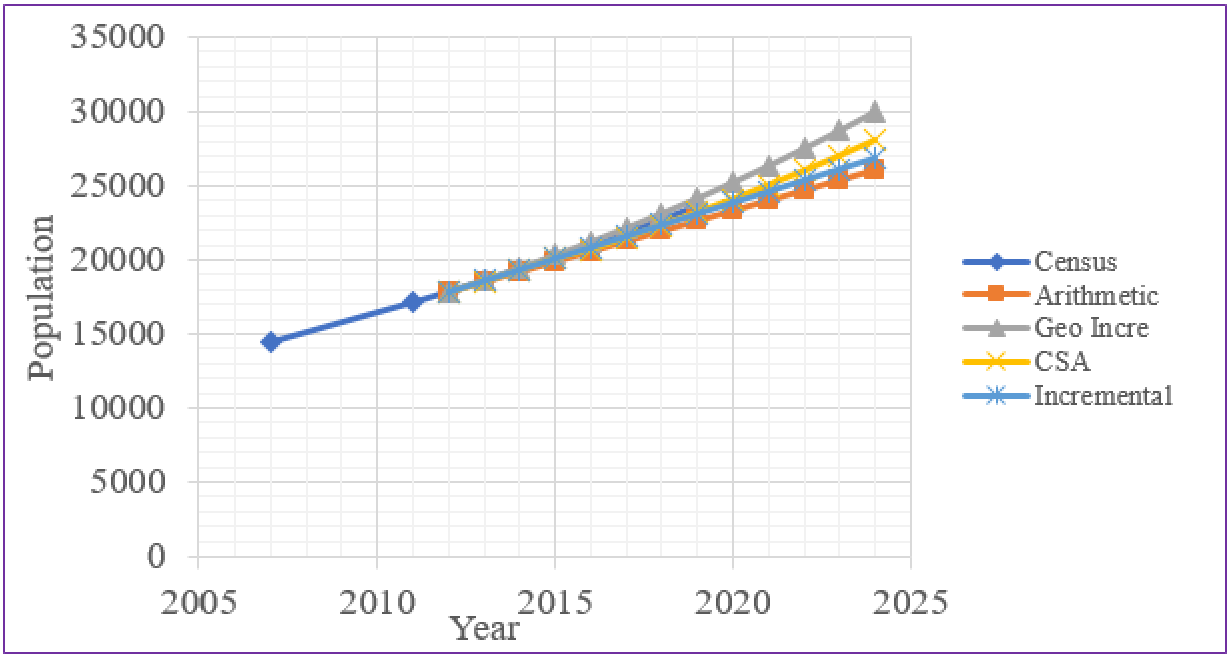

Figure 5

Tulu Bolo town census population plotted with projection for various methods

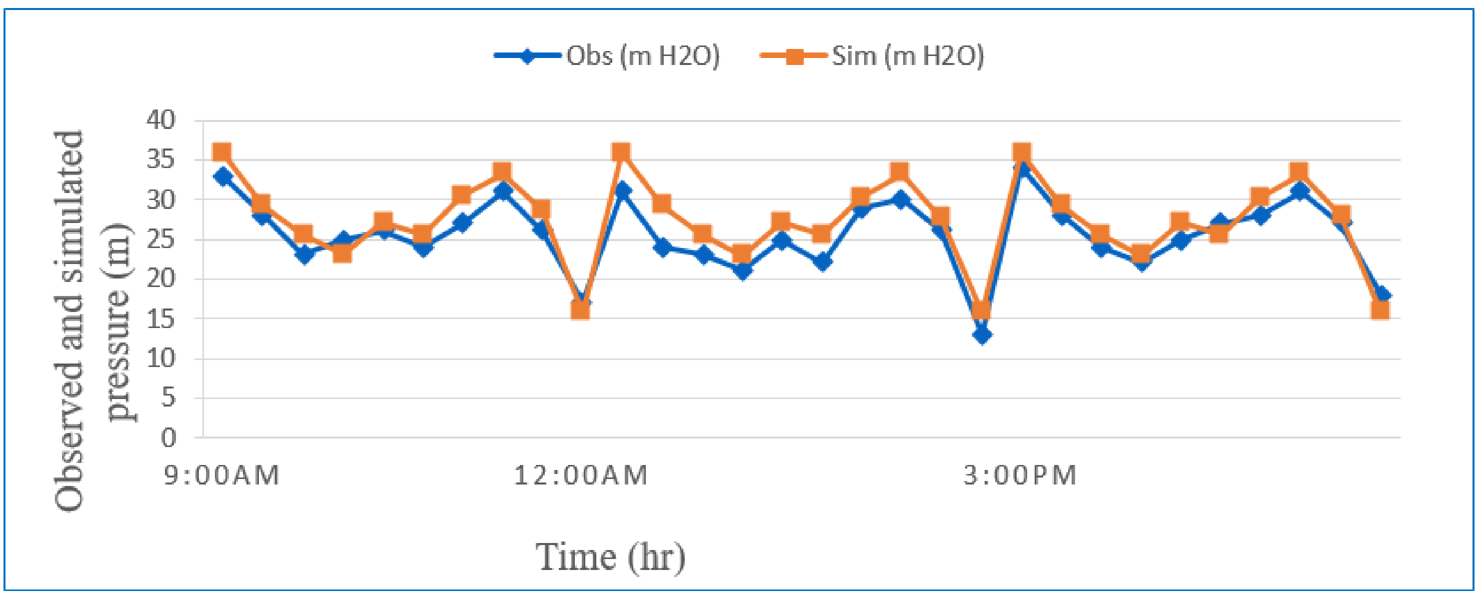

Figure 6

Observed and simulated pressure correlation

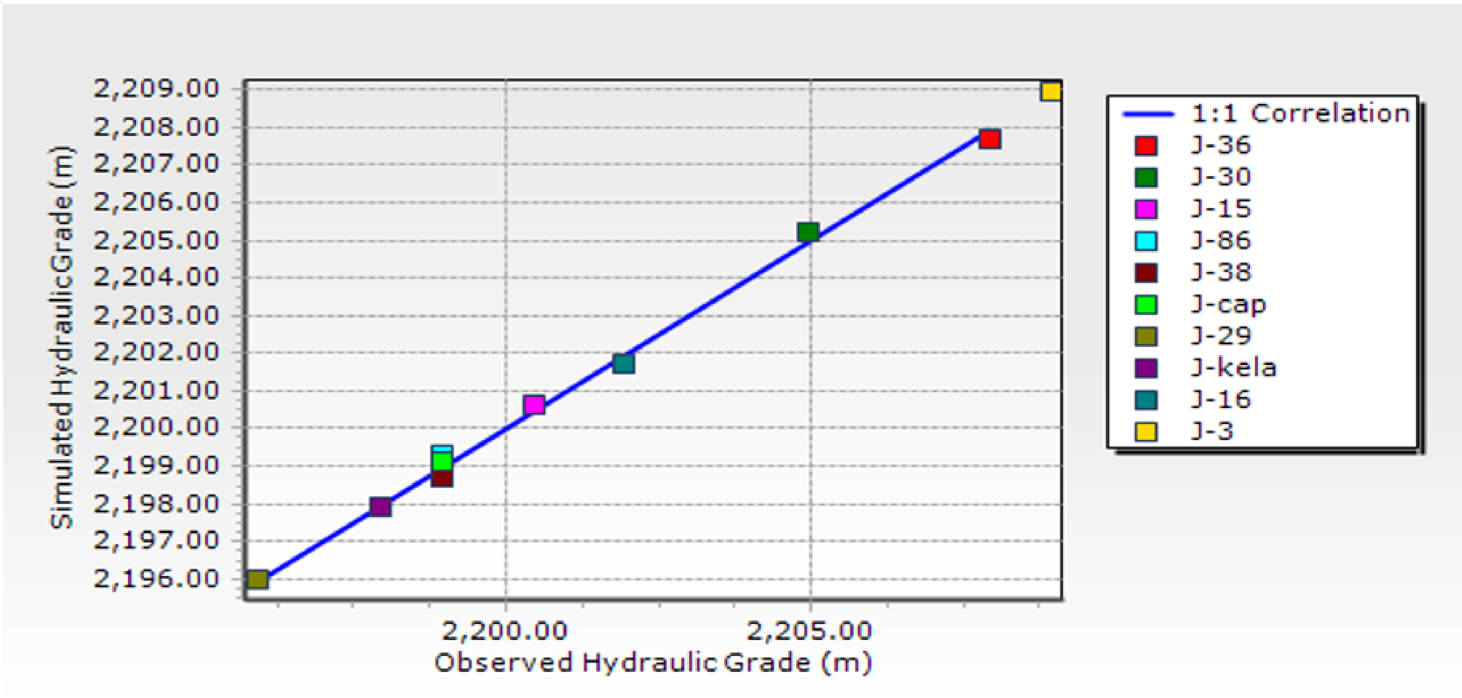

Figure 7

Calibration with Darwin calibrator in WaterGEMS

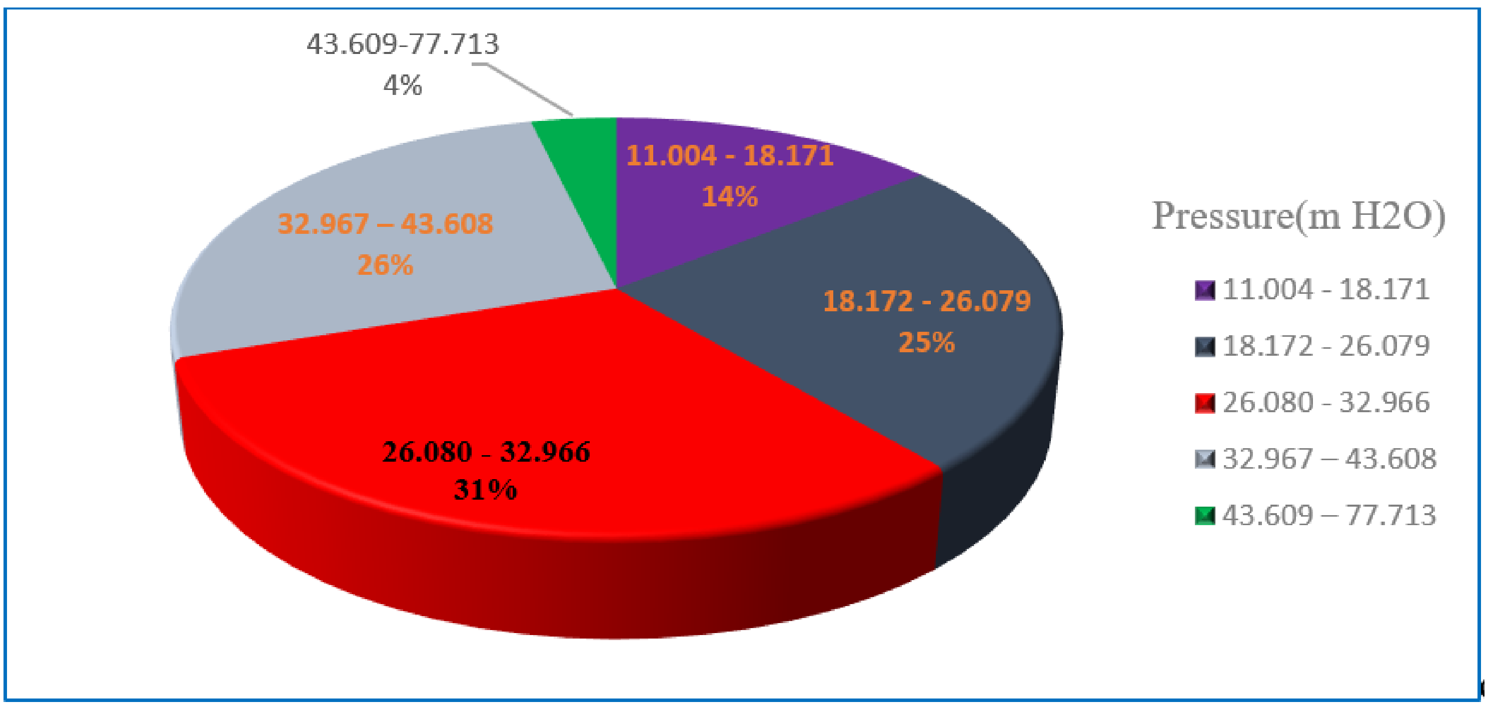

Figure 8

Junction pressure distribution percentage

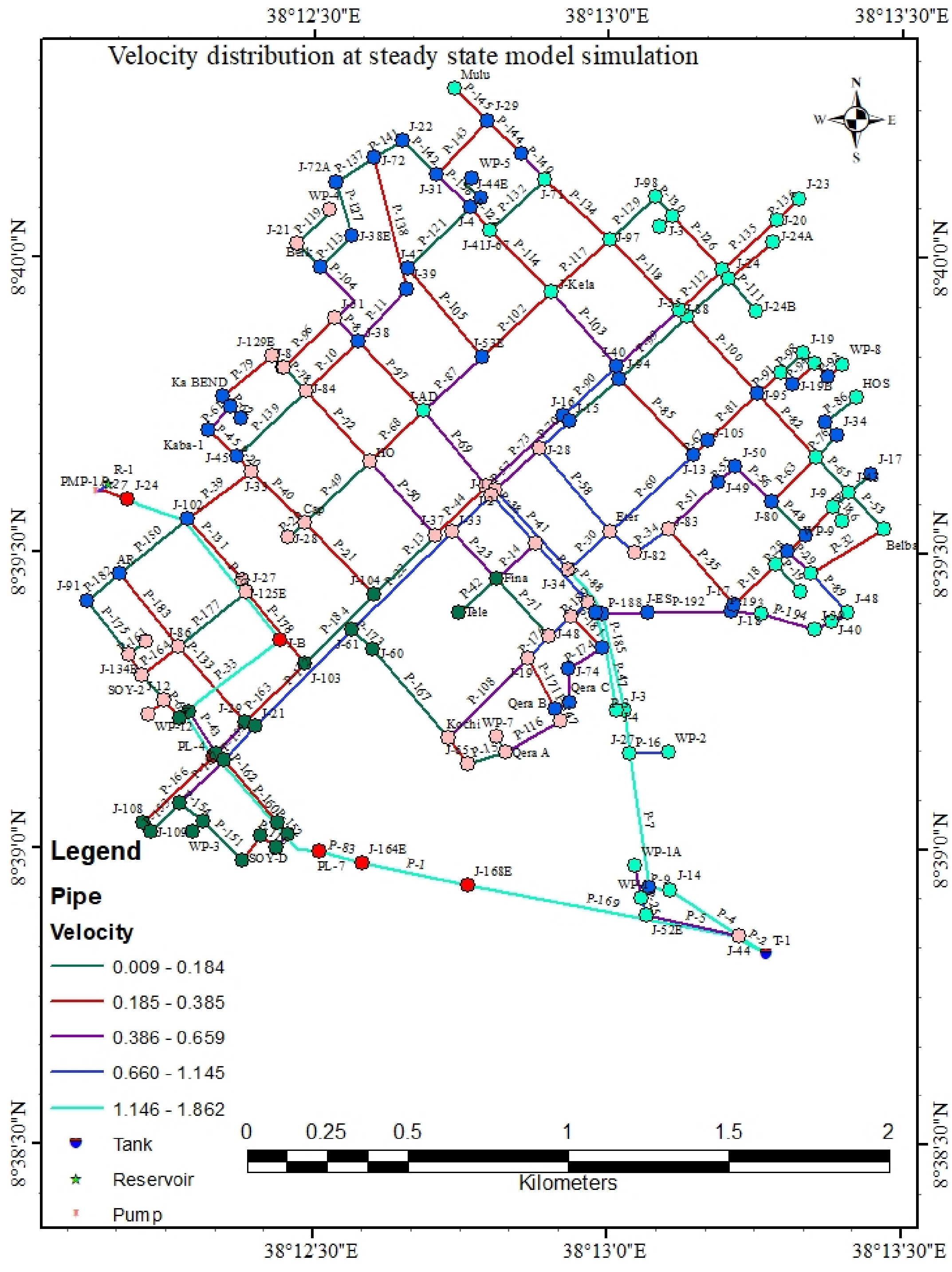

Figure 9

Velocity distribution at steady state simulation

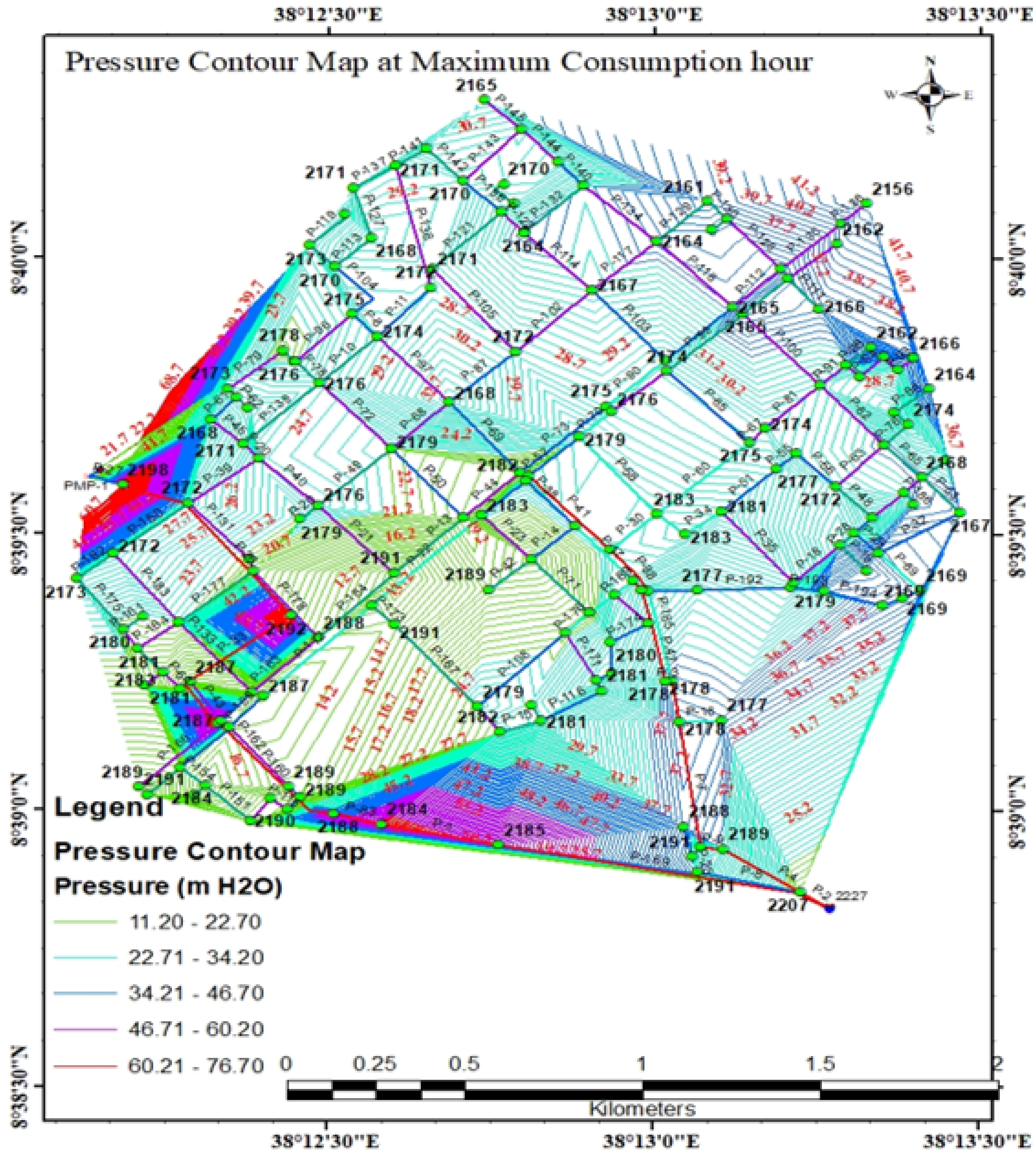

Figure 10

Pressure contour map of nodes at maximum consumption hour