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Demand Allocation Pattern for Consumption Points in Domestic Water Distribution Networks: A Case study of Ilam Campus

R. Momenzadeh*, R. Azarm and R. Aghamajidi

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Abstract

Water resource allocation plan requires more attention due to population growth and increased demand for water. Earlier researchers have focused on modern water allocation optimization methods. In order to allocate demand to consumption nodes in Ilam campus, Water GEMS and ArcGIS software were used. Shapefiles for bordering the study area boundary locations, node elevation, and population density in different parts of the university were prepared using ArcGIS software. Hydraulic simulation for allocation to each of the nodes was carried out with respect to population density, point load data, and area load data. Results showed that the maximum amount required for water distribution network with respect to population density was 30.48 liters per second. Also, the maximum need for the network with respect to point load data and area load data were as 27.23 liters per second. The water transmission line has the ability to pump approximately 17.61 liters per second while the amount needed for distribution network is exceeding this figure. As a result, the transmission line design is not appropriate.

Keywords: Demand Allocation, Water Distribution Network, WaterGEMS.

Introduction

Iran is located on the world arid belt in Asia with a precipitation average equal to one-third of the world average. Hence, it is vital to be able to optimize water consumption by suitable allocating of demands in consumption points. It is on the basis of such considerations that exploitation licenses are issued for applicants. The amount of allocable surface water and groundwater to various consumptions and needs in watersheds is determined based on priorities and qualitative limitations as well as the possibility of transferring allocation from consumption to another. Estimating the subscribers' consumption amounts is one of the most important engineering principles in planning a drinking water distribution system. Since the selection of distribution networks pipes diameter is directly related to water consumption amount of each node, overestimation of consumption amount leads to the increased distribution network diameter which, in turn, increases the operating cost. Another consequence is waterlogging in the network due to failure to reach the allowed limit of water speed and bad quality of water distribution. Zaman Zadeh et al. (2006) studied water efficient distribution methods with respect to demand. They specified a method which minimizes excess water while maximizing operating efficiency. Tabesh and Dini (2008) proposed a model for predicting one-day water consumption in the vicinity of Tehran based on meteorology parameters and past consumption data using multilayer perceptron neural networks and back-propagation educational algorithm. Results of this study showed using limited information, a neural network with two hidden layers with one and seven neurons, experts could come to a correct estimation with 80 percent accuracy. Boustani and Ansari (2011) studied the effectiveness of management approaches with respect to water consumption. They reported that effective management strategies include informing managers, decision-makers and concerned persons of various methods of demand management and charging the consumers full water costs. Kiafar et al. (2011) investigated optimized water allocation in Sufi Chay of Azerbaijan's water and drainage network using a genetic algorithm. They concluded that allocated water exceeded the optimized level. Moradi sabzkouhi et al. (2013) carried out a field study on maximum coefficient demand in rural water distribution networks of northeast of Khuzestan. After installing electromagnetic flow meters and measuring demand flow in 7.5-minute intervals for one year, the daily demand pattern and maximum coefficients were obtained. Results indicated that there is a significant difference between obtained maximum coefficients and suggested figures in standards. Baumberger et al. (2007) compared the demand allocation using population information, land use, and registered information of subscribers' consumption methods. The effect of each of these aspects on water distribution networks was assessed and discussed. Using field measurements of pressure equivalent height and crossing

R. Momenzadeh*
MSc, Civil Department, Islamic Azad University, Sepidan Branch, Iran.

R. Azarm
Assistant Professor, Civil Department, Islamic Azad University, Marvdasht Branch Iran.

R. Aghamajidi
Assistant Professor, Civil Department, Islamic Azad University, Sepidan Branch, Iran.

***E-mail:** rezamomen7173@gmail.com

flow rate in pipes in various conditions of use, Kang and Lansey (2011) suggested a two-step method for estimating demand and roughness coefficient in water distribution networks. The related algorithm was evaluated in two average real scales and the obtained results showed good operation of this model. Giustolisi and Walski (2012) investigated the components of demands in domestic water distribution networks and classified the demand into four components of pressure dependent demand, volumetric demand, fire need, and leak. The results showed that common models of domestic water distribution networks analysis named demand based analysis was not as efficient as pressure dependent demand models. Dini and Tabesh (2014) developed a new model for simultaneous calibration of demand pattern and Hazen-Willims coefficient in water distribution networks using incorporation of ants' optimization model and EPANET2 software. The proposed method was evaluated for a two-ring network and a real large-scale network. The results showed the method to be suitable. Roozbahani et al. (2015) proposed a multi-purpose model for water allocation stability of Sefid Rud basin in Iran considering environmental, social, and financial aspects. The model used programming method based on various weight compounds. Results showed that the proposed model could allocate 83 percent of water of basin to beneficiaries in a sustainable manner while the environmental demands were met, too. Wang et al. (2015) studied allocation of domestic water resources under uncertainty of water and demand in Urumqi. They proposed multistage twofold accidental programming to support domestic water resources management. Results indicated that the developed model can manage the uncertainty of accidental parameters and variants by incorporating twofold accidental programming parameters to multistage optimization programming. Pérez and Sanz (2015) studied demand pattern calibration in water distribution networks using pressure and flow rate sensors. Selecting the kind and the place of the sensors plays an important role in exact calibrating of networks. Three kinds of sensors including pressure sensors, flow rate sensors, and mixing of these two sensors were used successfully in a real water distribution network. Zhou et al. (2015) presented an optimized allocation model (IOAM) for a complex system of water resources management in Yang Jiang basin in Guangdong province in China. The results showed that this proposed model can balance supply and demand for sustainable development of society, finance, and environment. The above literature review indicates the shortage of studies in the field of demand allocation pattern to consuming points in domestic water distribution networks. This issue considered in this study by using ArcGIS and Water GEMS software.

Materials & Method

In this study, the pattern of demand allocation to existing spaces in water distribution network of Ilam University was investigated. Ilam University with more than 141.7 hectares area is located on the northwest of Ilam city and at 46°,22´,06 till 46°, 23´,19 east longitude and 33°,38´,55 to 33°,39´,37 north latitude of geographical scope and in 1475 meters above of sea level (figure 1). Now, the drinking water of Ilam University is supplied by one well. Water is pumped in two stages and is transferred to drinking water storage tanks of the university by a transfer line with 4.5 km longitude and 150 and 200 mm diameters made of steel and cement asbestos. The maximum flow rate of transfer line pumping is equal to 17.61 LPs. In the next stage, water is distributed into university by pipes made of steel and cement asbestos. This network encompasses 8076 maters pipe (of 13 to 496 meters' longitude) and 61 consuming nodes that pipes diameters varied from 76.6 mm to 213.2 mm. Hazen Williams's coefficient of pipes is considered 130.

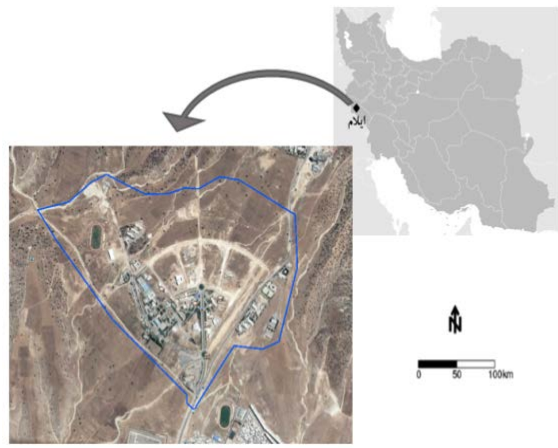

Figure 1- the site under study

In this research, after preparing network map and drawing the map in AutoCAD environment, it was transferred to ArcGIS environment and then the intended layers were georeferenced. Also, file slopes were created for the borders of the studied area as well as the borders of existing places in the area, height of existing points and population density in various units were entered into WaterGEMS. The created file was seen in WaterGEMS software as a background.

In this software, first suggested path of pipes and nodes according to streets locations and the spaces in university was drawn. In the next stage, pipes specifications including pipe number, first node, last node, pipes diameter and longitude, Hazen Williams coefficient, node numbers, and consuming flow rate of each node were entered into WaterGEMS software and then the speed, flow rate and decreasing pressure of each pipe and the pressure of all nodes were calculated. Wherever the water speed in the pipe or the pressure amount in node were not suitable based on the design bases, the calculations were repeated after changing pipe diameters to gain acceptable results. In order to allocate height to network nodes, Point file was created in ArcGIS software with different height. For allocating consuming water to each consuming nodes, three methods of population data, point load data, and area load data were used.

In the first method that is based on population data, there is a need for one polygon layer in which the area dedicated to each of the network nodes is defined. The next layer is a polygon layer, too; the population data of each existing uses in it was entered as a person in each hectare. Per capita consumption data of each person is defined as a liter in a day in this layer. The two polygon layer needed in ArcGIS software was made. Demand amount allocated to nodes was determined by mixing the two polygon layer and per capita consumption data. In the second method or consumptions data, in ArcGIS software for each event in university, one demand node was defined in pointwise manner and the required fields were defined in it. Demand allocation to consumption nodes was carried out as explained below:

Complying with billing meter aggregation condition, the researchers defined one polygon layer and one-point wise layer in ArcGIS software. Area allocated to each network node was specified by Thiessen Polygons in polygon layer. Information related to each existing event such as educational, cultural etc. spaces was entered into one of the fields related to pointwise layer. Water GEMS software can allocate all of the uses in dedicated area to each network nodes to the same node. Complying with nearest node condition, the researchers defined a two-point wise layer in ArcGIS software. The first layer included network nodes data that is the beginning and the end of the pipes. Information related to consumptions of each available uses such as educational, cultural etc. spaces was related to second pointwise layer. Water GEMS software allocated consumptions of all the uses to the nearest network node by mixing the two layers.Complying with nearest pipe condition, the researchers defined a two-point wise layer like the nearest node manner and a layer related to pipe. After mixing the layers in the Water GEMS software, the nearest pipe was allocated to consumptions of each available uses. The intended flow rate based on the four conditions specified below was allocated to the node of beginning or end of the pipe:

A: Equal distribution manner: allocating the same flow rate to both nodes
B: Distance weighted manner: allocating more flow rate to nearest node and less flow rate to further node
C: Closest node manner: allocating all of the flow rate to nearest node
D: Farthest node manner: allocating all of the flow rate to farthest node

In the third step, the demand of each node was obtained by using area of region and flow rate amount. This method included:

- Equal flow distribution: dividing total flow rate between network nodes in an equal manner
- Proportional distribution by area: dividing total flow rate between network nodes considering polygons area which allocated to nodes

Discussion and conclusion

Studying population density of university consumption

All of the spaces in university with various uses like residential, educational, services and welfare, religious, dining, facility and sport were named. People's accommodation places such as dormitories, guest houses and homes in Ilam University were under the title of residential use. Educational environments including colleges, educational- administrative centers, laboratories, library, and workshops were under the title of educational use. Places like shopping centers, banks, security centers, telecommunication and post centers, bakery etc. were named welfare and services use. Mosques were called religious use. All of the places related to water and wastewater, power and gas affairs were called facility use. All of the sport places including educational and recreational were called sport use. According to population statistics and available maps of university comprehensive plan, university uses density obtained as table 1.

Table 1- uses specifications (Rah Ab Kavan (2009) consultant)

Type of use	Area (ha)	Calculated population Due to end of project	Gross density (person per ha)
The residential	17/0483	2050	120
Training	18/3768	12570	684
Service and welfare	4/3456	400	92
Religious	0.1688	170	1007
Restaurant	0.4273	1900	4447
Utility	2/2665	60	26
Sport center	7.9949	600	75

In order to allocate the demand of each network nodes in Water GEMS polygon and pointwise layers and per capita consumption was used as in figure 2, which illustrates the allocated area to each network nodes. Also, the proposed paths of pipes and nodes considering streets location and the spaces in university can be seen in the same figure.

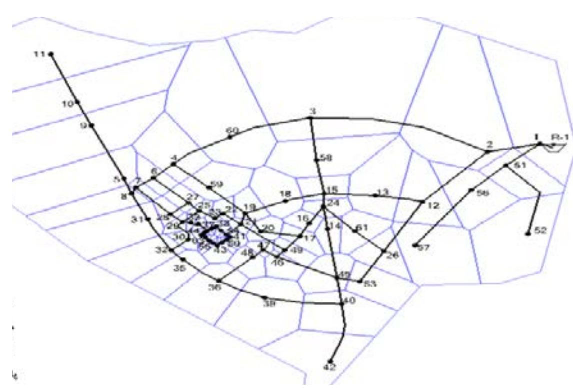

Figure 2- Polygon layers dedicated to each network nodes

Results of the First Method

According to figure 3, in this method, two polygon layers are needed. The first polygon layer is related to polygons allocated to each network nodes (like s13, s12, s56 and etc.). The second polygon layer named consumption points polygon layer (like P1, P2, P3 and etc.) included each uses in the university with a specified population density. The population density of various uses in university suggested as one person per hectare. Demand for all the consumption points' polygons which are in polygon layer dedicated to each network nodes is allocated to the related node. According to the figure, it is clear that demand for P1 polygon and parts of P2 and P3 is allocated to number 13 node.

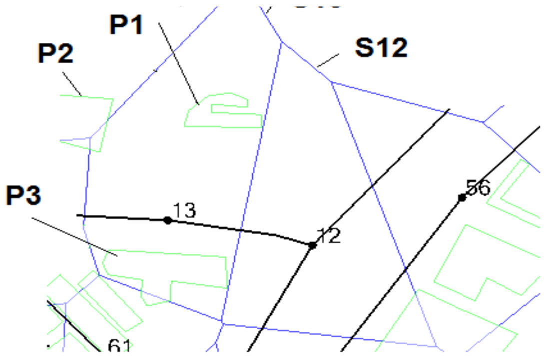

Figure 3- demand allocation pattern to nodes using the first method

The nodes demand profile in which horizontal axis of profile is the distance between water supply sources to number 11 nodes is shown in figure 4. The vertical axis of that is the demand of each network nodes in terms of s. Per capita consumption data of each person defined in population density as equal to 250 liters in a day. The nodes that had the most population density took the highest allocation. Therefore, most of the demands allocated to nodes number 8, 13 and 18.

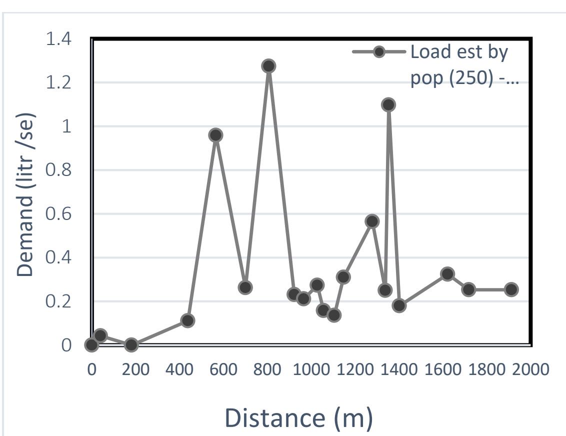

Figure 4- Nodes' demand profile using the first method

The Results of the Second Method

Billing meter aggregation and the nearest node method

Figure 5 shows the demand allocation pattern to nodes by using billing meter aggregation and the nearest node method. Composed layers for applying in the nearest node method are nodes' layer (like 15, 18, and 19 and etc.) and consumption layer (like A, B, C, and D and etc.). For instance, in this method, all demands of consumption points A, B and C were allocated to the nearest node, namely, node number 18. Composed layers for using in billing meter aggregation method are nodes' layer (like 15, 18, 19 and etc.) and allocated polygon layer (like S18, S15, S24 and etc.). The total demand in each polygon is allocated to its related node in itself. For instance, in S18 polygon, there are three consumption points A, B, C. Hence, these consumptions allocated to node number 18.

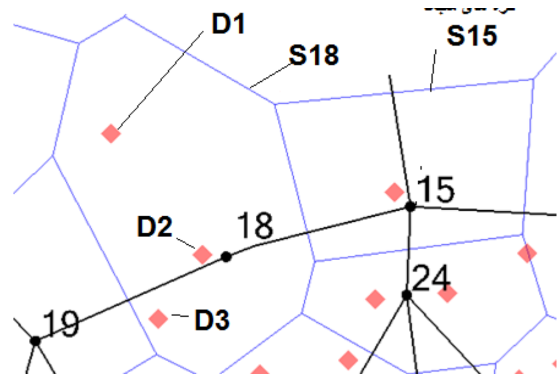

Figure 5- Pattern of demand allocation to nodes by using the first method – billing meter aggregation and the nearest node

The allocated demand to nodes' profile is shown in figure 6. Because consumption point numbers in each polygon are equal to the nearest node of network, the demand profile is consistent with billing meter aggregation and the nearest node method. The most demands allocated to nodes number in respect 18, 6 and 13.

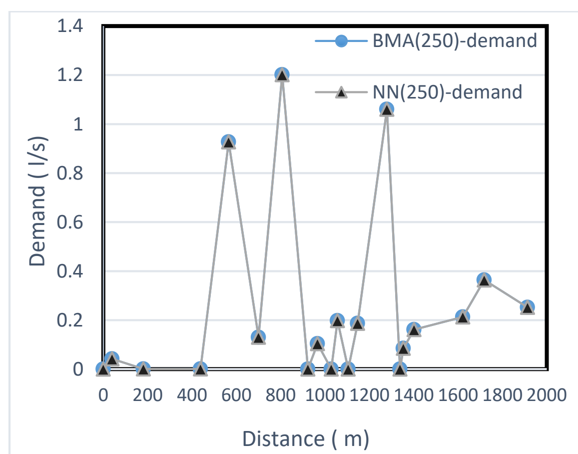

Figure 6- Nodes' demand profile by using the first method – meter aggregation and the nearest node.

The nearest pipe

In this method, the consumption point demands are allocated to the nearest pipe. After finding the nearest pipe, the related demand is divided between the nodes of the beginning of the pipe and the end of the pipe. As figure 7 shows, pipes layer (like P1, P2, and P3), nodes' layer (like 4, 6, 7) and consumption points layer (like D1, D2, D3, D4 and etc.) are needed. It is clear in figure 7 that three pipes P1, P2, P3 are connected to node number 6. The nearest consumption points to this pipe are 5 points including D1, D2, D3, D4, and D5. Therefore, the part of demand of these 5 points is allocated to node number 6. Figure 8 shows nodes' demand profile using the nearest pipe method. Since after finding the nearest pipe, demands are divided based on the same distribution modes, the weighted distance and the nearest node to the beginning and the end of the pipe, various values obtained for each network nodes.

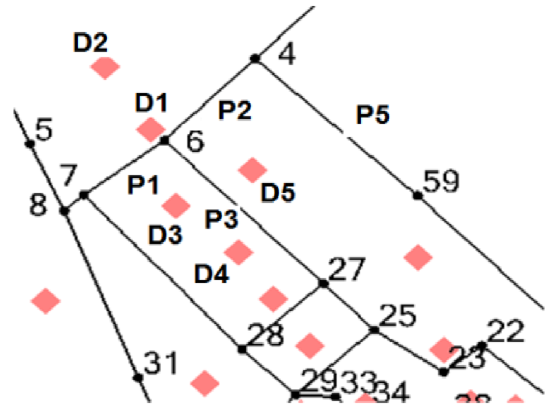

Figure 7- Pattern of allocation demand to nodes using the second method – the nearest pipe.

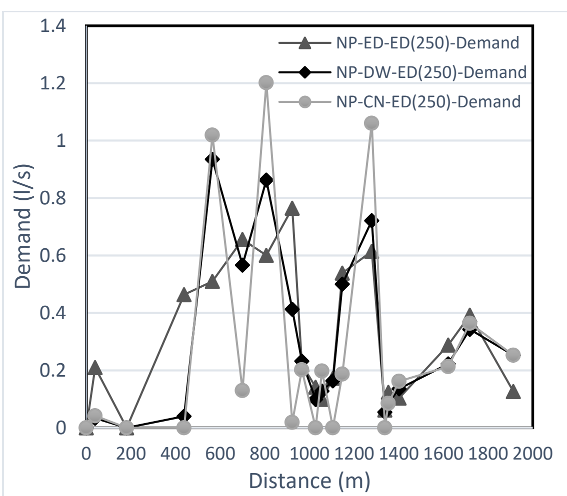

Figure 8- Nodes' demand profile using the second method- the nearest pipe.

The Results of the Third Method

In this method, one polygon layer that included the total area of the university is defined. All flow rates of obtained demand from the first method are allocated to this polygon. Two other needed layers are similar to composed layers in billing meter aggregation method. Nodes' demand profile is shown in figure 9 using flow identical distribution and proportional to area distribution method. In flow identical distribution method, total demand was divided between network nodes equally. However, in proportional to area distribution mode, the most demand allocated to the node which has the most area. In this method, the most demand was awarded to node number 13.

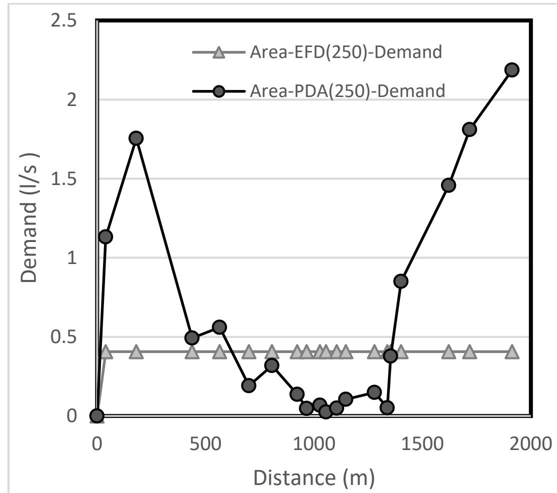

Figure 9- Nodes' demand using the third method

Minimum, maximum and average values of demand are shown in table 2 in different manners.

Table 2- per capita consumption variations

Method comparison	Maximum Demand (l/s)	Average Demand (l/s)	Minimum Demand (l/s)
Method1	2/88	0/45	0
Method 2 number of consumption point	5/16	0/41	0
Method 2 – closest joint t	5/16	0/41	0
Method 2 – closest pipe 1	3/08	0/41	0
Method 2 – closest pipe 2	3/92	0/41	0
Method 2 – closest pipe 3	5/16	0/41	0
method 3 -1	0/41	0/41	0/41
Mrthod3 -2	3/38	0/41	0/01

Comparison of per capita consumption variations

Person's per capita consumption of different resources was reported between 150 to 250 liters in a day in urban and rural communities. In this research, per capita consumption variations for the three above methods were done in university distribution network and the results are explained in table 3.

Table 3 – Per capita consumption variations

Per capita consumption (litr / 24 hours)	150	200	250
Network Demand(l/s)	18/29	24/39	30/48
Network Demand mehod 2. 3(l/s)	21/32	24/27	27/23

According to this table, it is determined that the network need in the first method varied between 18.29 to 30.48 liter per second. Also, the network need in the second and third methods varied between 21.32 to 27.23 liters per second.

Conclusion

This research was planned with the purpose of demand allocation pattern to consumption points in domestic water networks distribution in Ilam University. The results of the study are as follow:

- Combination of hydraulic modeling and geographical data system can allocate demand pattern to consumption points in water distribution networks.
- Pattern of demand allocation to consumption point in water distribution network in Ilam University calculated by using three methods including population density, pointwise consumption data, and consumption data as area.
- Water distribution network requirement in population density method was obtained between 18.29 to 30.48 liters per second. Also, the network requirement in pointwise and area consumption data calculated between 21.32 to 27.32 liters per second
- Transfer line was able to pump maximum flow rate equal to 17.61 liters per second while the need of distribution network is higher equal to maximum 30.48 liters per second. This fact shows inappropriate designing of transfer line.
- In the first and third methods, total demand of network was determined by using available data by the software; however, in the second method, total demand of network was given to software as input data to be able to divide demands between nodes.

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