Potential of water pipeline bursting using stochastic approach in Geographical Information System

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Abstract. A pipe bursting is one of the major problems in water distribution systems. This problem resulted in losses, particularly in water wastage or shortage and infrastructure damages. Furthermore, several organisation and authorities do not have systems or database for water management monitoring, leading to a difficulty in monitoring and update the condition of the pipeline. Geographical Information System (GIS) can help to develop a geospatial database for the water distribution network; to determine the high potential of pipe to be burst and identify the areas affected by the pipe failure. In this study, the potential of pipe to be burst is determined using a stochastic approach to get the probability of the potential failure, which based on four factors; age, pressure, material and diameter of the pipe. A valve isolation trace function from ArcGIS tool is then used to determine the area affected by the pipeline failure. Results from the analysis are to produce maps of high potential pipeline bursting and the affected areas. The findings could help the management to monitor the conditions of the water pipeline regularly, detecting early warning, preparation for the pipe's replacement and notify the residents to make initial preparations if the pipe has a potential to burst.

1. Introduction

The common problem in a water distribution system is a pipe bursting. The pipe bursting is a condition, where the pipes break due to high flow in the pipe that causes rupture to the pipe walls. Over time, it causes the water to overflow to the ground. Pipe bursting caused by many factors such as the soil type, age, water pressure, diameter and material of the pipe [1]. It is very crucial to study the potential of pipe bursting to ensure enough supply of treated water to the optimum demands throughout the areas. Study area involved in this study is the main UTM Campus in Johor Bahru, excluding the Faculty of Bioscience, located in Taman Universiti, Skudai. The Pejabat Harta Bina (PHB) manages water management in UTM. There are more than 130 water pipe burst cases in UTM from 2014 to 2017, as recorded by PHB. This problem had caused several blocks of nearby dormitories experienced in water disruption for several days. Also, residents do not have time to make early preparations and have been disrupted their daily work for a few days. The worst-case when the burst pipe causes the roads flooded with plenty of water that can damage the structure of the road.

The study is aimed to determine the potential of water pipe burst using a stochastic approach in GIS. The valve isolation trace in ArcGIS 10.3 software is used to recognize the valves that related to the chosen pipeline based on its connectivity at upstream and downstream of water pipelines. Many researchers used a stochastic approach by using the probability of multi-factor characteristics of the pipeline. A random variables behavior is used, make it a suitable method to determine potential pipe bursts, such as pipeline condition and its surrounding [2]. For example, the pipeline failure on corrosion processes used stochastic approach using multi-factor nature of phenomena [3]. A study on pipeline defect by considering external factors such as soil type, the structure of pipe, the process of inspection and maintenance was using the same approach [4]. Markus and the team also used stochastic to modelling growth of pipeline corrosion using the probabilistic model [5]. Therefore, in this study, it focuses on four factors only, which are pipeline water pressure, diameter, age and material of the pipe.

2. Methodology

Figure 1 shows the flowchart to conduct the study. It starts from preliminary study to gather the information and data until analysis and validation phase. The following subtopics explain the details of the phases involved;

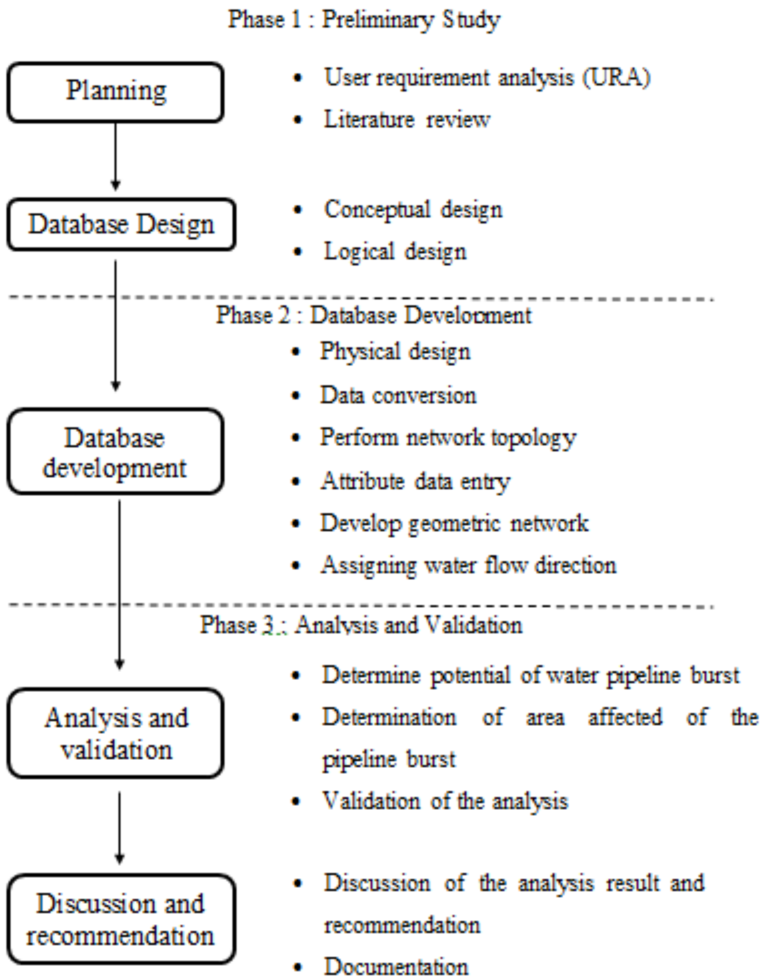

Figure 1. A flowchart of study methodology that contain of three phase, which is preliminary study, database development and analysis and validation phase.

2.1.1. Preliminary study

An overview and understanding of water pipeline distribution system through interview, literature review and site inspection is necessary. This stage is crucial to get the raw data of water pipeline from data sources and identify the problem and solution. Database design is needed to develop the conceptual and logical model for the water pipeline database. The conceptual and logical design is a model that extracts the object in real-world into information data and show logical relationships among the objects.

2.1.2. Database development

Initially, the data provided by PHB does not have the correct coordinate system and scale. Therefore, the pipeline layout needs to be digitized and adjusted according to the base map. Topology rules are applied to the converted data to validate the relationships among shared geometry feature in the database. This topology clean up the drawing to ensures there is no overshoot and undershoot problem in the pipeline feature. It also ensures the entire feature such as valves, meter reading and hydrants connected to the pipelines. Then, attribute data for each feature are added in the database based on the information extracted from the data provided. A physical model of water pipeline distribution database is created in the ArcGIS containing several feature classes in the dataset. Then, the geometric networks are generated to maintain feature connectivity between lines and point features. It controls how the features connected and make tracing within the network efficiently. All points and lines feature in the feature dataset are interconnected in this geometric network. After that, the flow direction is set by a user using a Water Utility Network Editing tool in ArcGIS, based on the digitized direction of the feature and site inspection.

2.1.3. Analysis and validation

The stochastic approach is a method that used probability in multifactor characteristic to determine a phenomenon. In this study, the determination of high potential water pipe burst is done by using probability from four factors. Table 1shows the weightage assigned to age of pipe (a), water pressure in the pipe (b), diameter of pipe (c) and material of pipe (d). Value 1 of the weightage means the criteria in the factor gives less impact to the pipe burst. Value 2 indicates the moderate impact on the pipe burst and value 3 gives the highest impact.

Table 1. The weightage assigned to pipe burst's factor, which is age of pipe (a), water pressure in the pipe (b), diameter of pipe (c) and material of pipe (d).

(a)

Weightage	Age of Pipe (years)
3	> 30
2	10 to 29
1	< 10

(b)

Weightage	Water pressure of Pipe (N/m^2)
3	> 30
2	10 to 29
1	< 10

(c)

Weightage	Diameter of Pipe (inch)
3	4, 6, 8
2	10, 12
1	15, 16, 21

(d)

Weightage	Material of Pipe
3	Asbestos Cement
2	PVC/UPVC/Poly
1	Mild Steel

Then, the total weightage is calculated for each pipe to rank the pipes into three categories, which are high, moderate and low potential to burst. Table 2 shows part of the weightage and rank table that applies in the water pipeline database. Field calculator tool in ArcGIS is used by creating a Python script to assign the rank for each pipe based on the criteria in Table 2. Different colours have been set at the symbology of pipeline feature to differentiate the rank. For instances, red colour for high potential, yellow for moderate potential and green for the low potential of pipe to burst.

Table 2. Part of weightage and rank table that used as a reference in creating Python script to assign rank for each pipe in the water pipeline database.

Age	Pressure	Material	Diameter	Total	Rank
3	3	3	3	81	High potential pipe burst
			2	54	High potential pipe burst
			1	27	Moderate potential pipe burst
		2	3	54	High potential pipe burst
			2	36	Moderate potential pipe burst
			1	18	Low potential pipe burst
		1	3	27	Moderate potential pipe burst
			2	18	Low potential pipe burst
			1	9	Low potential pipe burst
	2	3	3	54	High potential pipe burst
			2	36	Moderate potential pipe burst
			1	18	Low potential pipe burst
		2	3	36	Moderate potential pipe burst
			2	24	Low potential pipe burst
			1	12	Low potential pipe burst
		1	3	18	Low potential pipe burst
			2	12	Low potential pipe burst
			1	6	Low potential pipe burst
	1	3	3	27	Moderate potential pipe burst
			2	18	Low potential pipe burst
			1	9	Low potential pipe burst
		2	3	18	Low potential pipe burst
			2	18	Low potential pipe burst
			1	6	Low potential pipe burst
		1	3	9	Low potential pipe burst
			2	6	Low potential pipe burst
			1	3	Low potential pipe burst

The area affected due to high potential of pipe burst was determined by using Valve Isolation Trace. The configuration file of the valve isolation trace needs to be configured to fit the water pipeline distribution in the study area. The number of valves, location of the valves, the number of buildings, building's name and the number of population was determined when the valve isolation trace has done.

Validation for the determination of high potential pipeline burst is done by changing the attributes in the database to its original value before repairing works are performed. The attributes of the pipeline are changed, and the analysis was repeated to identify which pipes have high potential to burst. In this study, the pipe burst cases that happened in 2014 are observed. This is to ensure the cases happened in 2014 agrees on the predicted analysis performed.

3. Results and discussions

Figure 2 illustrates part of the main pipeline developed in the database that contains the attribute of pipe material, pressure, diameter and year of installation. This information would help to determine the potential of pipe burst in the study area..

OBJECTID *	SHAPE *	Material	Diameter	Pressure	Year
1	Polyline	Asbestos cement (AC)	12	72.2415	2015
2	Polyline	Asbestos cement (AC)	12	72.2415	1984
3	Polyline	Asbestos cement (AC)	8	56.9683	1984
4	Polyline	Asbestos cement (AC)	8	56.9683	1984
5	Polyline	Asbestos cement (AC)	8	56.9683	1984
6	Polyline	UPVC	8	56.9683	2016
7	Polyline	UPVC	8	56.9683	2016
8	Polyline	Asbestos cement (AC)	8	56.9595	1984
9	Polyline	Asbestos cement (AC)	8	61.9595	1984
10	Polyline	UPVC	8	61.9595	2015
11	Polyline	Asbestos cement (AC)	8	66.9592	1984
12	Polyline	Asbestos cement (AC)	8	66.9592	1984
13	Polyline	PVC	8	65.271	2018
14	Polyline	Asbestos cement (AC)	8	65.271	1984
15	Polyline	Asbestos cement (AC)	8	65.271	1984
16	Polyline	Asbestos cement (AC)	8	65.271	1984

Figure 2. Attribute table for water pipeline distribution database.

Meanwhile, Figure 3 shows a map of potential pipe burst in UTM based on the results of the stochastic approach. Area of Lingkaran Ilmu, Kolej Tun Fatimah and Kolej Tun Razak are predicted to have a high potential of a pipe burst. This is due to the water pressure in that area is about 50 to 70 N/m², which are more than normal water pressure. The material of pipeline used is Asbestos Cement (AC) type, an old type pipe that has a high failure rate. The pipeline was installed in 1984, which the age is more than 30 years. These characteristics combination lead to the high potential of pipe bursting. By having this database, its help the management to monitor the pipelines and avoid a large of water wastage, as broken pipes can be determined earlier. They also can make early preparation for pipeline maintenance, as they have a detailed of pipelines that should be replaced. Also, the pipe burst cases map can be used as a reference to study the pattern of pipe burst in details.

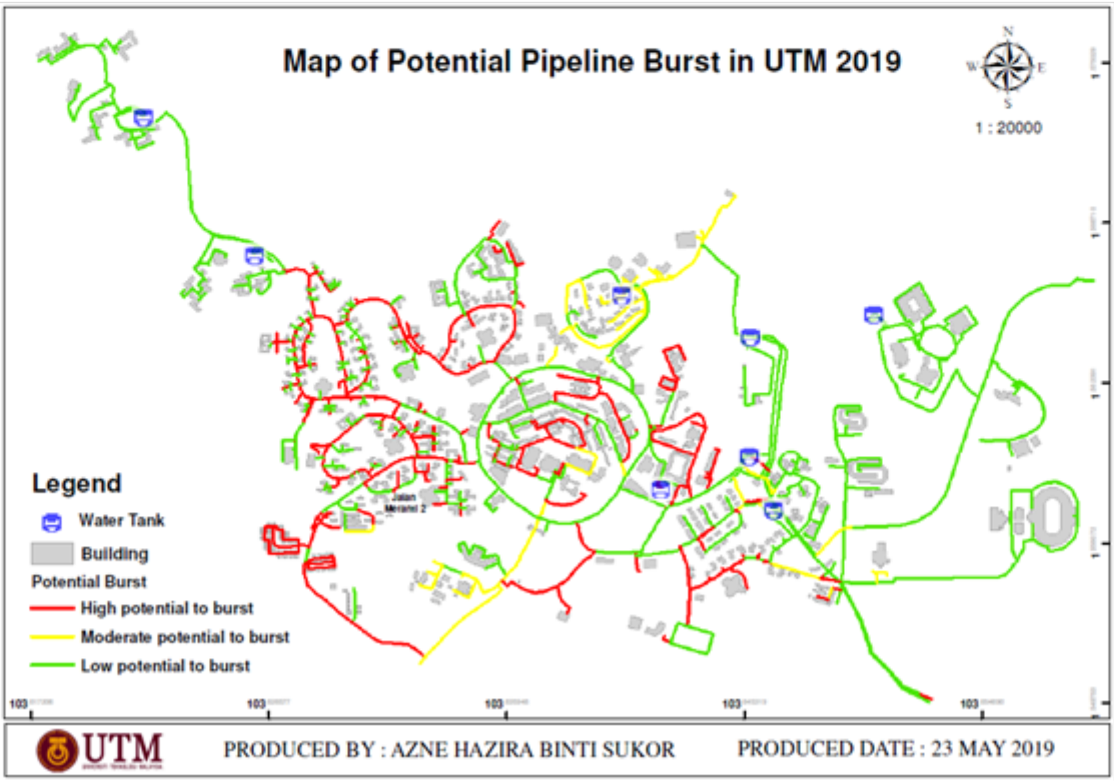

Figure 3. Map of potential water pipe burst in UTM for 2019. A red line represents high potential of pipe burst.

Figure 4 shows in details the percentage of high potential pipe burst based on zones in UTM. Lingkaran Ilmu has the highest percentage of high potential pipe burst compares to other zones. This is because most of the pipelines in that zone are more than 30 years old, which are easier to burst due to the dilapidated condition of the pipe. In addition, Lingkaran Ilmu is a hilly area which needs high pressure of water to meet the water demand. Therefore, management can use the results to monitor the zone regularly and avoid excessive wastage of water if the pipe burst can be detected earlier.

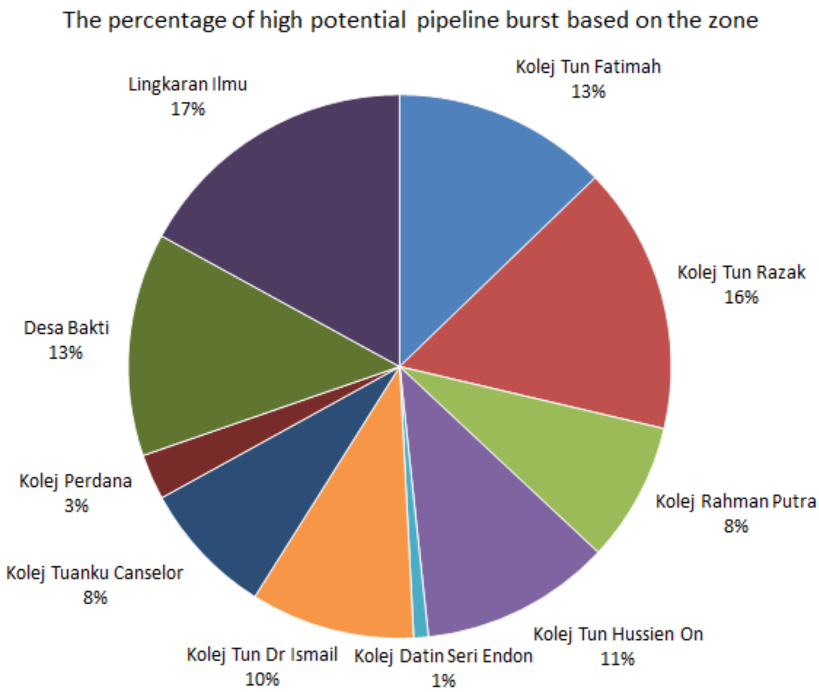

Figure 4. High potential pipe burst based on zones in percentage.

There are several scenarios that can be used to represent the result of the area affected due to pipe bursting. For example, in Figure 5, it shows that if the pipe burst occurred at the Jalan Meranti 2 (a yellow star), there are two valves need to be closed. Water supply disruptions will occur when the valves are closed, and there are 10 dormitory buildings will be affected. About 1000 residents will be affected if this situation happened. All the information of the result is retrieved from the database when valve isolation trace function was run. This helps in determining which buildings are involved, identify which valves should be closed and how many people will be affected by the closure of the water.

The validation result indicated that 23 from 29 cases of pipe burst recorded in 2014 has 79%, of which were correctly predicted to have high potential to burst. While another 6 cases were predicted to have a moderate and low potential to burst. This is because of other factors of pipe burst that not being consider in this study such as soil type, soil movement and depth of the pipes.

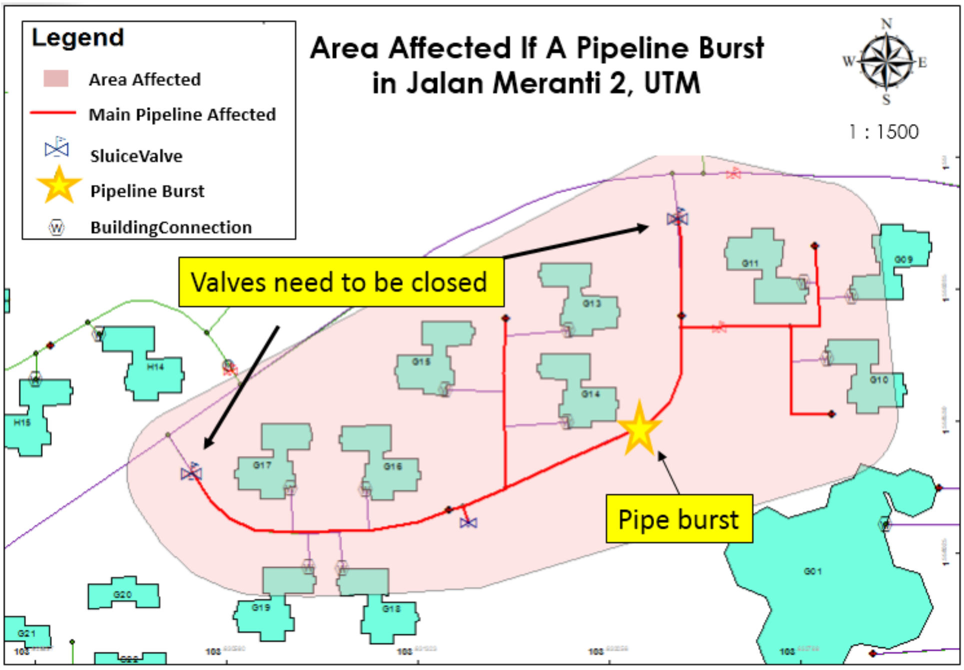

Figure 5. Area affected map of water pipe burst (red color) in Jalan Meranti 2.

4. Conclusion

Finding from the results showed that the high potential of pipeline burst could be determined using a stochastic approach. Areas affected by the pipe bursting can also be identified using a Valve Isolation Trace tool in ArcGIS. An affected area due to pipe burst is helped in giving an early warning to the residents to make early preparations. Information from the database can also be used to give information on pipe properties and flow characteristics in the pipelines. The database developed can reduce water wastage due to water leaking if detected early and to avoid other infrastructure damages. However, the results can be improved by considering other factors such as soil types, depth of the pipeline installed and soil movement effects. More information on mechanisms of pipeline failures may contribute more accuracy in the analysis. This study would help the organization in managing water pipeline distribution, particularly in monitoring the pipes that are at risk for bursting based on the database developed and to help them plan the best design for water pipeline system in future.

5. References

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6. Acknowledgement
The authors would express gratitude to Pejabat Harta Bina UTM, Syarikat Air Selangor and Syarikat Air Johor for all the guidelines, data and knowledge throughout this study. We also thank and acknowledge the Universiti Teknologi Malaysia and Ministry of Higher Education of Malaysia for their financial supports on the research grant Vot Number Q.J130000.2527.11H52.