Journal of Water and Wastewater, Vol. 32, No. 5, pp: 44-60

Geospatial Modeling of Urban Sewage Network Operations Based on DRASTIC Model (A Case Study of Isfahan)

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(Received Aug. 23, 2021 Accepted Oct. 11, 2021)

To cite this article:
Katiraei, F., Gharagozlou, A. R., Alesheikh, A. A., Hemmasi, A. H. 2022. "Geospatial modelling of urban sewage network operations based on DRASTIC model (a case study of Isfahan)"
Journal of Water and Wastewater, 32(5), 44-60. Doi: 10.22093/wwj.2021.300889.3171.

Abstract

In recent years, old urban sewage networks have encountered numerous flaws, leading to several important problems in the environment, such as groundwater pollution, excessive growth of tree roots inside sewer pipes, etc. To tackle such problems, innovative approaches must be practiced in urban sewage networks operations. To this aim, a spatial model based on "predictive analysis" and smart technology in the sewage network operation management is needed. Our proposed model was firstly applied for the city of Isfahan to evaluate and predict possible accidents in the urban sewage network. Our model is based on DRASTIC model and Geographic information system. The sewage accidents were assessed by combining the results of DRASTIC model and Getis-Ord Gi* index. This model could assess the previous sewage accidents and predict the probability of future accidents in cities, as well as their environmental risks. In this study, the intention was to identify the hot spots of accidents in the sewage network using GIS; then by studying the factors affecting the accidents, and geological and environmental parameters, a spatial model was designed. Combination of the Getis-Ord Gi* index and DRASTIC model is the main innovation of this research. In the study area, the following items were determined as the most important factors in the sewage accidents: 1- soil type, 2-inappropriate infrastructure, 3-inappropriate pipes with older age, 4-lower diameter. Finally, this model showed that there was a significant relationship between spatial and environmental indices in the study area. Also, the significance value obtained from the statistical analysis of the relationship between pipe diameters and sewer network accidents was equal to 0.004 and the significance value obtained from the statistical analysis of the relationship between pipe life and such events based on Kendall and Spearman tests were calculated as 0.05 and 0.37, respectively.

Keywords: Sewage Network, GIS, Getis-Ord Gi*, DRASTIC, Groundwater, Environment.

1. Introduction

1-1- The problem and background

The growth and development of cities, and the significant rise of the urban population in recent years have all led to the increasing complexity of the urban network management. If the deterioration of water distribution networks and sewage collection networks, and other networks of urban facilities are added to this complex problem, the management of urban facilities will be much more challenging, the management of urban networks will be much more difficult and challenging. Today, paying special attention to environmental issues in planning and urban development activities should be regarded as an effective step toward improving the environment and citizens' lives. For this reason, experts and researchers have continually sought to assess the environmental impacts of urban projects in order to move toward more sustainable development (Bolouri et al., 2020).

The rapid expansion of urbanization around the world has led to significant challenges, such as lack of construction space, increasing worn-out textures, traffic, lack of living facilities and environmental pollution. The main reasons for these problems are overcrowding and activities expansion, and economic and social development in the urban areas, which are beyond the current capacity of cities (Irankhahi et al., 2017).

Rapid urbanization throughout the world has led to many urban problems in a large number of megacities. Urban problems including buildings construction, shortages, traffic congestion, lack of facilities, environmental pollution, and imposed challenges in the face of sustainable development have frequently troubled these cities (Irankhahi et al., 2017).

Groundwater velocity is too low; however, it is a useful factor in the polluted aquifer remediation of organic and radioactive materials or bacteria, and virus pollutants. In this situation, the long-time groundwater holding may cause the pollutants removal (Faryabi, 2019).

Groundwater is an important source of water supply for drinking, agriculture and industrial purposes. In semiarid and arid regions, groundwater is typically reliable; it is the only source of water. However, rapid urbanization, industrialization and agricultural practices have resulted in the decline of groundwater quantity, as well as quality, across the world. Remediation of groundwater is difficult once it gets contaminated and the cost of remediation may be very high (Rajput et al., 2020).

Therefore, understanding factors that control the degradation of groundwater, which have become more sensitive over years due to the intensive use of the natural resources and increased human activities, is a challenge and tackling it can have significant practical implications for water resources management (Ferchichi et al., 2018).

Groundwater is a natural drinking water resource often subjected to severe human impacts. Several programs and models are required to preserve the optimum groundwater quality; so, the management of this vital natural resource has become a worldwide priority.

Groundwater is the most important water resource in arid and semi-arid areas like Iran. If groundwater resource is polluted, its remediation will be costly and time-consuming; this is often recognized when the remediation is almost impossible. Monitoring groundwater quality is one of the most effective tools to improve our understanding of hydro-chemical systems, leading to the sustainable development of various pollution types of water resources that appear to predominate in groundwaters, such as heavy metals, fertilizers, pesticides and other organic chemicals. The leaching of various pollutants through the unsaturated zone and the groundwater one can lead to the contamination of these areas. This process differs from one place to another (Chen et al., 2019).

Aquifer vulnerability map is a key forecasting and prevention tool that has been recognized for its ability to delineate vulnerable areas as a result of anthropogenic and geogenic activities. It consists of evaluating the ability of a pollutant to move from the earth surface into the groundwater (Berhe Zenebe et al., 2020).

Existence of important sources of pollutants and points caused by human activities on the ground and the penetration of these pollutants into the aquifer can reduce the quality of groundwater. Therefore, preventing groundwater pollution is essential in the management of groundwater resources. Groundwater remediation is, however, a long process and pollution is often diagnosed when it becomes almost impossible to decontaminate the aquifer. One of the best ways to prevent groundwater pollution is to identify the vulnerable areas of the aquifer. Nowadays, the sustainable management of water resources, the prediction of the pollution risk and the protection of these resources are of great importance. During the last decades, the sewage networks have been constructed in some cities; however, because of the age of these networks, some of them have started to collapse, causing damage to the network. Identifying potential damages and the reasons for their occurrence can, therefore, help prevent or reduce the effects of these damages; it may also contribute to network reconstruction. The effective parameters in creating accidents in urban sewage networks are divided into two groups:

1. Environmental parameters: In these parameters, human has no direct role. Among these environmental parameters, the natural and gradual corrosion of urban

facilities and acidic materials of pipes surrounding the soils can be mentioned.

2. Human parameters: In these parameters, the human has a direct effect on their occurrence. Among these parameters, dropping rubbish into the sewage manholes can be mentioned. Because some of the manhole valves have been stolen or broken.

Hence, it is essential to safeguard the quality of these resources. Also, some of the other environmental hazards such as groundwater pollution, excessive growth of tree roots inside sewer pipes, where the pipes are corroded, etc., can be mentioned (Katiraei et al., 2021).

The DRASTIC[1] method was developed in the US Environmental Protection Agency[2] to evaluate the groundwater pollution potential for the entire United States. DRASTIC is an acronym standing for depth to water; net recharge, aquifer media, soil media, topography, impact of the vadose zone and hydraulic conductivity. It is an index model designed to produce vulnerability scores by combining several thematic layers. GIS[3] is designed to collect data and produce spatial layers by applying a series of interpolations and overlay analysis (Al-Abadi et al., 2017).

DRASTIC system is the most widely used method to evaluate intrinsic vulnerability for a wide range of potential contaminants. It is an overlay and index model designed to produce vulnerability scores by combining several thematic maps. The application of the DRASTIC approach, while revealing some advantages, also suffers from some drawbacks. Indeed, the outputs of the DRASTIC index strongly depend on the available information (from different sources and at different mapping scales). This may lead to different assessments for the same case study region (Poorbalighi, 2021).

The first step in planning and designing urban networks is spatial data gathering. The classic methods cannot satisfy the modern network's demands. The modern technology has provided such novel methods as Lidar and Laser Scanning for the rapid spatial data collection and Ground Penetration Radar[4] for the underground spatial data gathering. GPR is a non-destructive geophysical technique frequently used to investigate the interior of a medium, particularly for cultural heritage issues. It can also accurately assess the level of moisture inside structures, such as ancient walls or decorated pavements (Ferrara and Barone, 2015).

Therefore, it seems necessary to design a model that can combine an environmental model and a geographical one to predict the environmental hazards of urban sewage network accidents.

GIS has been a potent tool for management, processing, visualization and spatial data analyses. When associated with spatial statistics techniques, it may be a support tool for the preparation and monitoring of urban and regional planning. (De Moura and Procopiuck, 2020).

GIS projects are implemented in urban services for providing information, designing, engineering and managing urban facilities related to such information. Also, GIS can play an effective role in the mechanization of programming and utilization trend of urban facilities.

While much research has been done on the technical foundations and hydraulic principles of sewers, as well as the reconstruction of municipal sewage network and network accidents, designing a model that can be used to assess the environmental risks of sewage accidents and their occurrence by combining a spatial model and an environmental one, considering the indices used, has yet to be achieved.

One of the important limitations of this research was the lack of a complete database on the vulnerability of groundwater in Isfahan region due to accidents in the municipal sewage network. Also, the use of traditional methods of spatial data retrieval such as ground mapping or photogrammetry, despite the high accuracy, due to the high cost and long data retrieval to convert and prepare maps does not meet the needs of such large networks. New technology has provided new methods such as lidar (laser scanning) for fast extraction of spatial data for terrain and GPR for detection and removal of basement, as well as the internal parts of a structure with the required accuracy (Javid et al., 2010).

With review design methods of urban sewage network in Nabovat town of Ilam in Iran and with use of information related to climatic topographic features and statistical information such as population and per capita effluent methods, proper design of urban wastewater networks to minimize incidents in these types of networks were studied (Bolouri et al., 2020).

Also, Hadjmeliani et al. reviewed sudden collapse in the form of a large hole that was observed in one of the main roads of tripoli near sewage pipes. The original wall thickness was reduced catastrophically. Damages in pipe wall allowed fluid leaks, cavities in soil and collapse of pavement layers. The condition underneath the road resulted in this big hole (Hadjmeliani, 2015).

Kheirandish et al. studied about effect on sewage network on groundwater quality in Bojnourd. The results showed that the discharge of solid waste in the landfill site and domestic wastewater would severely affect the groundwater quality, while implementing the municipal sewage system will improve the quality of groundwater significantly in the period of 15 years (Kheiandish et al., 2020).

Also, the purpose of Pourbalighi et al. research was to map the vulnerability of groundwater in the Aisin

[1] Depth to Water Table, Net Recharge, Aquifer Media, Soil Media, Topography, Impact of Vadose Zone, Hydrolic Conductivity (DRASTIC)

[2] US Environmental Protection Agency (USEPA)

[3] Geographic Information System (GIS)

[4] Ground Penetration Radar (GPR)

plain of Hormozgan using DRASTIC and GODs[1] methods and with the help of GIS (Pourbalighi, 2021).

In this regard, De Moura and Procopiuck provided a view of the geographic distribution of basic sanitation services in Parana, Brazil. Temporal distributions, spatial patterns and clusters were determined using 2000, 2010 and 2016 data. Local Indicators of Spatial Association[2] and Getis-Ord Gi*(d) were then used to identify the presence of possible clusters and hot spots in households with sanitation services. The study provided strong evidence that the service rates for sanitary sewage were significantly lower than those for water supply and waste collection. Waste collection was proved to have the highest service rate in the study area (De Moura and Procopiuck, 2020).

Yang et al. also showed the relationship between the APTT[3] reference values and altitude by correlation analysis. Linear regression analysis and curve analysis were employed to predict the APTT reference values in the whole country (Yang et al., 2020).

Onwe et al. in view of increasing depletion in groundwater resources, mainly because of excessive mismatch in waste dump sitting, applied a GIS-based approach to estimate the spatial distribution of soil and subsurface rock properties to delineate the potential areas. The results showed that human population density, drainage pattern and flow direction, food-vulnerable areas, depth to groundwater, soil texture, rock type, restructure features (faults, fractures) and slope nature were the influential factors on sitting waste dump/landfall, especially for the purpose of checking groundwater contamination and possible pollution (Onwe et al., 2020).

Mohamadi Dehcheshme and Shanbehpour studying crisis management in Yasuj urban water facilities, by using GIS analysis and the SWOT[4] evaluation model, investigated the strategic plan for improving and modernizing the drinking water facilities of Yasuj city with emphasis on passive defence. In this study, the use of camouflage methods was considered to build diversion tanks to deceive the enemy, increase the security cameras, and upgrade the telemetry systems of wells and reservoirs in the city, as well as their exact location, for the complete coverage of water facilities with the help of GIS as the effective solutions for crisis management. In this study, while emphasizing passive defence in the urban water network, solutions were proposed to improve the security of such networks, which could be used to prevent those accidents in the urban sewage network which are caused by human factors. These methods can also be used for sewage network. But we need to use manholes features instead of valves in this study. On the other hand, the type of sewage accident is different by water distribution accidents (Mohamadi Dehcheshme and Shanbehpour, 2021).

Rezaei Nodeh et al. also estimated the risk of gas transmission lines using the GIS indexing method near Borazjan city. Risk estimation was performed using two indicators of total hazards and leakage effects, each of which consisting of several sub-indicators and showing the main causes of accidents in the gas pipeline network. To implement the method, the selected pipeline indexing system was divided into 52 parts with a fixed length of 1000 meters. The risk estimation process was performed for each part of the pipeline network (Rezaei Nodeh et al., 2019).

Yang et al. applied trend surface analysis, the variation function, kriging interpolation, and Getis-Ord Gi* statistic to reveal the spatial characteristics of the values. The results showed a significant positive correlation between APTT reference values and altitude. APTT values for females were greater for a longer period of time, as compared to the males, in several of the same areas of China. The spatial contact forms of the APTT reference values of the healthy Chinese were mainly “high-high” and “low-low,” which was in accordance with the first law of geography. The altitude had a significant positive correlation with APTT reference values. The spatial contact forms of the APTT reference values were mainly “high-high” and “low-low” in China. Trend surface analysis, the variation function, kriging interpolation, and Getis-Ord Gi* statistic were also utilized to reveal the spatial characteristics of the values. The results showed a significant positive correlation between the APTT reference values and altitude. The APTT values for females were more for a prolonged period of time, as compared to the males, in several of the same areas of China (Yang et al., 2020).

Norhafizah et al. also used Getis-Ord Gi* spatial statistics to identify hot spots on the controlled-access expressway. The application of the method was demonstrated through a case study by using the reported road accident cases in North-South Expressway[5] (Norhafizah et al., 2019).

Wee et al., based on information obtained from the study of the hotspots of RTAs[6], especially those resulting in severe injuries, used multiple agencies to direct resources efficiently. Data was obtained from the National Trauma Registry. The RTA locations were remapped onto the Singapore map; spatial statistical techniques were then used to identify hotspots by the Getis-Ord Gi* algorithm (Wee et al., 2020).

[1] Groundwater Occurance Overall Aquifer Class Depth Table of the groundwater (GODs)

[2] Local Indicators of Spatial Association (LISA)

[3] Activated Partial Thromboplastins Time (APTT)

[4] Strengths Weaknesses Opportunities Threats (SWOT)

[5] North-South Expressway (NSE)

[6] Road Traffic Accidents (RTAs)

Attwa and Zamzam also demonstrated that the joint use of GA[1] with Structure-Based Model[2] could be helpful in the recognition of subsurface layer distributions with non-smooth interfaces. However, the ACB[3] approach is more practical for lateral heterogeneities determination within the same rock unit in comparison to SBM with the GA approach. The results indicated that the waterlogged areas and wastewater migration pathways were mainly controlled by the drainage networks and subsurface structure. The wastewater leakage was directed to the nearest surface canal to reduce the environmental and geotechnical problems, which were expected to appear in the study site. We anticipated that the suggested approach of GIS and DCR[4] data, using advanced inversion schemes, could improve the accuracy of DCR interpretation and be applicable in a robust and cost-effective way to practice wastewater leakage management in desert urbanization projects (Attwa and Zamzam, 2020).

On the other hand, Jarray et al. showed Groundwater vulnerability maps could be used as a tool to help decision makers to protect groundwater resources from contamination. The vulnerability of the Mio-Plio-Quaternary shallow aquifer (Southeast Tunisia) was assessed using a DRASTIC model based on the GIS (Jarray et al., 2017).

Mohammadi et al. by performing spatial analysis on urban sewage network accidents in Ardabil, considering 722 cases, investigated the sewage network of this city by the end of 1995. For data analysis, Geographical Weight Regression[5], density (Kernel) and scatter pattern were used. The findings showed that most sewage incidents occurred in central neighbourhoods, densely populated and informal settlements, and the old areas of Shahrokh (Mohammadi et al., 2018).

The present research was intended to evaluate the environmental hazards of urban sewage network accidents by combining a spatial index and an environmental model. By using the DRASTIC environmental model, the environmental hazards of urban wastewater network accidents and the effective factors in the occurrence of such accidents were investigated; then the hot spots of accidents were located in the GIS by map and the historical data by examining the records of the previous accidents which obtained from water and sewage company, using the Getis-Ord Gi* index for assessing the past accidents and predicting the future ones. The combination of these two models and the assessment of environmental hazards threatening the municipal sewage network could be considered as an innovation of this research.

According to the studies in crisis management, environment, urban sewage networks and applications of the Geographic information system in the mentioned fields, it is possible to design a spatial model that combines the Getis-Ord Gi* index and drastic model by examining the records of the previous accidents to assess the environmental hazards caused by urban wastewater network accidents. The proposed method for the model includes the following steps:

1- Developing a model for assessing the environmental hazards of urban sewage network accidents by combining the geographical information system (Getis-Ord Gi* index) and the DRASTIC environmental model.

2- Modeling network weaknesses by examining the records of the previous accidents and historical data in GIS map.

3- Determining the appropriate method to change the conditions or minimize the events in the critical points of the network to prevent accidents and environmental hazards, especially groundwater pollution, dampening of historical monuments, and the infiltration of the tree roots into sewage pipes.

Information analysis method has the following steps:

A- Examining the records of the previous accidents in the study area according to the various factors causing them and identifying the hot spots of accidents and creating the Getis-Ord Gi* index.

B- Weighing each of the records using the DRASTIC model and compiling the final model by combining this model with Getis-Ord Gi* as a raster map based on the Getis-Ord Gi* index combining an environmental model with a spatial index, the possibility of extending this model to other urban utility networks, recording environmental information in descriptive information tables of municipal sewage network incidents is a special innovation of this research. Empirical aspect of this model means that, at any time, by updating the information of accident records and also adding a database of new incidents to it, it is possible to update the model and so, is considered a research innovation.

2. Materials and Methods

In this study, at first, the needed data were gathered using the documents and library information. By performing the field study, the pipes and manholes were identified and their location was entered into the ArcGIS software. Attribute information related to the events and accidents was then gathered using the data bank of a part of Isfahan wastewater authority; in a five years period from 2015-2020, it was recorded in a data table (Katiraei et al., 2021).

By linking the database to the wastewater network map, the initial data was prepared. This model, which was created in the GIS medium, has the ability to assess

[1] Genetic Algorithm (GA)
[2] Structure-Based Model (SBM)
[3] Active Constrain Balancing (ACB)
[4] Direct Current Resistivity (DCR)
[5] Geographical Weight Regression (GWR)

and predict the accident occurrence. These events have been evaluated in different pipes with various materials, diameters, ages and lengths. Generally, the trend of accident changes in each year has a rising pattern because of the pipe age increase and fluctuating hydraulic situations.

The hypotheses of this research include the following:

1- Reviewing and analysing the records of urban sewage network accidents provides a suitable information base for designing a spatial model to assess the environmental risks of sewage network accidents.

2- The proposed model in GIS environment has the ability to assess and predict the possible situation of accidents and environmental hazards caused by them in the network.

3- By combining the drastic environmental model and spatial Getis-Ord Gi* index, a spatial model can be designed to assess the environmental hazards of the municipal sewage network.

At first, the evaluation design and prediction of events were provided. By considering the previous accidents and experts' comments, the effective factors can be classified as shown in Table 1.

From Getis-Ord Gi* statistics, for a more detailed study of spatial distribution hotspots or clusters with large amounts, cold spots or spatial clusters are used in small quantities. This statistic is in three classes 5, ± 2 ± and 1 ± and confidence levels of 92, 92 and 99 percent are calculated (Esmaili and Amini, 2021).

The basis of the Getis-Ord Gi* index is the neighbourhood density. If the value of a point is high along with the value of the neighbouring points, that area is part of a hot spot. Therefore, the total area for one of the points and its neighbours can be calculated relative to the sum of all points.

Getis and Ord developed the G statistical index to show the spatial patterns of the features, leading to presenting the Gi* index. In other words, Gi * is a local indicator indicating a high or low density of a pleasant structure.

The local statistics for Getis-Ord Gi* are expressed as follows:

The element Gi* represents the statistical significance and mirrors the degree of clustering and dispersion; the higher the Gi∗ value, the more clustered the high values of the hot spots; on the other hand, the lower the Gi* value, the more clustered the low values of the cold spots.

The formulas and the process of calculating this index are expressed in equations A, B and C, respectively.

In this relation, Gi* is the correlation coefficient of the incident I from n incidents. Since n is the number of sewage accidents. W is the spatial distance between points i and j, and Xi is a descriptive value for the point or complication i (Yang et al., 2020)

$$G_i^* = \frac{\sum_{i=1}^{n} w_{i,j}x_j - \bar{x}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{[n\sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2]}{n-1}}} \quad (1)$$

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{x})^2} \quad (3)$$

By using the Getis-Ord Gi* index, hotspots at the map were identified. As can be seen in the map, the distribution of hotspots in the study area varied depending on the diameter and material used in the sewer pipes.

By identifying the points on the map, where the Geis-Ord Gi* index is higher and known as hotspots, it can be determined which environmental or geological parameters are the cause of the accident at that point. After recording the spatial information of sewage network accidents in a period of time, GIS capabilities

Table 1. The effective factors on the event occurrence in the wastewater network

Accident factor	Wrong performance	Antiquity	Undesirable operation	Human factor
1	False channel bed building	More than 30 years	Without network washing	Dropping solids in manholes
2	Undesirable pipe quality	20-30 years	Without manhole levelling	Hitting by mechanical shovel
3	Wrong type of pipe	10-20 years	No holes in manholes and gas traps	Sewage acidity change
4	Wrong depth of pipe	0-10 years	Failure to conduct periodic inspections	Discharge of industrial wastewater into manholes

are used to analyse the data. In other words, Gi* is a local indicator indicating the high or low density of a cluster structure.

Getis-Ord statistic could then be used to identify accidents hotspots. This test assesses whether the clusters of crashes are statistically significant. The resultant z value expresses the high or low values of the neighbouring features.

Features with a high value may not be a statistically significant hotspot. To be a statistically significant hotspot, a feature should have a high value and be surrounded by other features with high values as well. A positive z score indicates a hotspot; so, the larger the z scores, the more intense the clustering; meanwhile, a negative z score indicates a cold spot and the smaller one shows the more intense clustering of the low values (cold spot) (Aghajani et al., 2017).

The DRASTIC model is based on the concept of hydrological status; it describes a combination of all geological and hydrological factors that can affect and control the movement of groundwater inside and outside the system in one area. DRASTIC index is developed for the assessment of groundwater vulnerability on the regional scale. The variables involved in this index are classified into three main categories: land surface factors, unsaturated zone factors and vadose zone (Amiri et al., 2020).

This index is based on the following four hypotheses: (1) ground surface pollution, (2) percolation of pollution into groundwater through precipitation, (3) water causing the movement of pollution, and (4) the minimum area of the DRASTIC-assessed zone, which was 0.4 km^2 (Venkatesan et al., 2019).

The procedure was intended to yield a systematic assessment of groundwater pollution potential in any hydrogeology setting.

The DRASTIC model considers seven hydrogeological parameters: depth to water table (D), net recharge (R), aquifer media (A), soil media (S), topography or slope (T), impact of the vadose zone (I), and hydraulic conductivity of the aquifer (C) (Iqbal et al., 2015).

The parameters of the drastic model used in this research are as follows:

1. Groundwater depth: This indicates the depth from the ground level to the water level; the greater the depth, the less the pollution.
2. Nutrition Network: This indicates the amount of water t penetrating from the surface of the earth and reaching the groundwater level. One of the main factors in the transfer of pollutants into the earth is the vertical movement of water.

The higher the nutrition, the greater the potential for groundwater pollution.

In this research, the population density was used as the main factor of nutrition; this is because the larger the population of the region, the greater the need to implement pipes with a larger diameter.

3. Aquifer environment: This refers to the consolidated or non-fortified geological materials that make up the body of an aquifer. This parameter determines the length and course of the groundwater flow system in the aquifer.
4. Soil type: The potential for soil contamination depends on the type of soil, particle size and the potential to absorb contamination in the soil. It is a salt study area in the east and a calcareous study area in the north.
5. Topography: It is related to the changes in the slope of the earth's surface. The slope of the earth's surface affects the amount of the infiltration of water and pollutants. Each passage is obtained by dividing the height of the manhole (Z) by the distance between the two manholes, which is usually 50 meters.
6. Unsaturated environment: The unsaturated area starts from the surface soil zone and continues at the water table. This parameter indicates the infiltration of the unsaturated area into the water surface and controls the path of the pollutants to the aquifer. The map is listed in the descriptive information table.
7. Hydraulic conductivity: The intensity of groundwater flowing under the hydraulic slope of the environment; the higher the number of contaminants, the greater the possibility of contamination, depending on the texture of the soil. It determines the movement and shelf life of the pollutants from the point of entry into the soil surface to the aquifer. Enhancing the hydraulic conductivity increases the potential for contamination. The hydraulic conductivity of the wastewater is defined based on the ground slope.

Combining the Getis-Ord Gi* index and the DRASTIC model is a new process used for the first time to model the events of an urban sewer network. In this study, the intention is to identify the hot spots of accidents in the sewage network using GIS; then by studying the factors affecting the accident, and geological and environmental parameters, a spatial model is designed to assess the environmental risks of such accidents.

2-1- Study area

Isfahan city, with a 3800 km sewage network and a history of nearly 50 years, is one of the areas that has recently had the highest number of accidents in the urban sewage network. Soils are mostly in saline and heavy clay areas and the penetration of the species in soils is very slow. As a result of evaporation, the surface of the mentioned lands is often covered with the white crust of salt and solvents in water; the soil texture near the river and mountain slope is lighter due to the presence of gravel and sand; so, water permeability is relatively fast and water retention is less in such soils. As we go further east, more salt is added to the soil.

In the table describing the information, the properties of the points with accident history are shown. These properties contain the exact address, the type of accident, pipe diameter, depth and material, the soil material, the date of accident and the probable accident location.

As can be seen, the manholes levelling in the northern part of the city is an important factor in the accident occurrence. In the central and western parts of the study area, the old age of networks was determined as an important factor in the accident occurrence.

Initially, points with a history of accidents in the study area were located on the GIS map; the descriptive information of these points was entered in the tables related to them. This information included the diameter of the pipes, date and address of the accident.

Fig. 1 shows the Isfahan wastewater networks map, after determining the previous event records. The wastewater network events in the study area can be divided into two categories:

1. The accidents related to the wastewater network failing and corrosion of pipes.
2. The accidents related to the wastewater network obstruction and rejection.

In the next step, hot spot points in some regions of the study area were determined. Those points had the most accidents in recent years; then those points were located in the GIS map in the study area. After that, the location of the pipes and manholes in the urban sewage network in the study area was shown in GIS map. Based on this information, we can manage the accidents in the study area. Fig. 2 shows the hot spots map of the Isfahan sewage network. Blue dots indicate low accident points (cold points) and the red dots represent the most accident points (hot spots) in the municipal sewage network. As can be seen, in the central parts of the city, where a historical and old texture can be found and more vehicles move, the rate of accidents in the sewage network was higher.

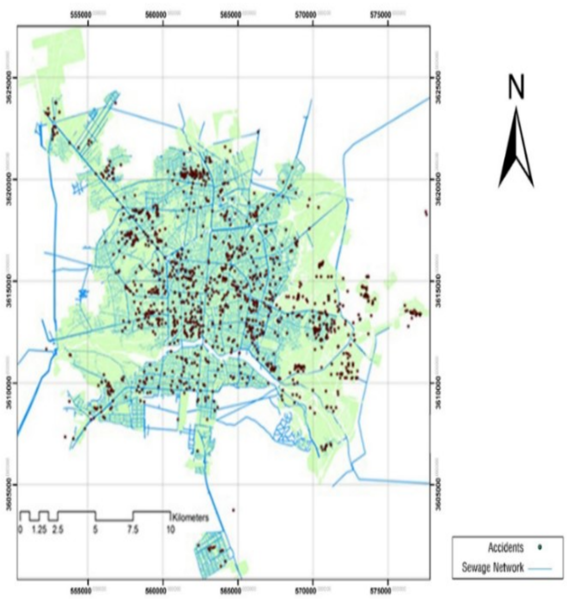

Fig. 1. The history of sewage accidents in Isfahan (2015-2020)

By designing the evaluation model and forecasting urban wastewater network accidents, this model can be applied to the other regions.

Using the network analysis in the ArcGIS software, the wastewater flow direction is determined in the network. By using this process, the location of the upcoming probable point of wastewater can be deduced (Katiraei et al., 2021).

Hosseingholi et al., using genetic planning, studied the number of clogs in the sewerage network of Isfahan in 1994 and 1995 and compared the results with the results of the neural network model. Parameters such as age, length, slope and burial depth of pipes as input and number of nodules were considered as the output of the model and the superiority of genetic programming method over neural network was determined for this purpose (Hosseingholi et al., 2020).

In Najafpour et al. groundwater pollution in Lenjan region in Isfahan province was considered by the role of quantitative and qualitative changes in groundwater over a period of 25 years. Uses were exposed to the aquifer. The central area of the study area to the north was exposed to pollution due to further industrial, urban and agricultural development and direct infiltration of effluent from these uses into the aquifer (Najafpour et al., 2018).

3. Results and Discussion

This research study introduced a comprehensive model to predict the accidents in the urban sewage network to assess its environmental damages. Hence, the outcomes

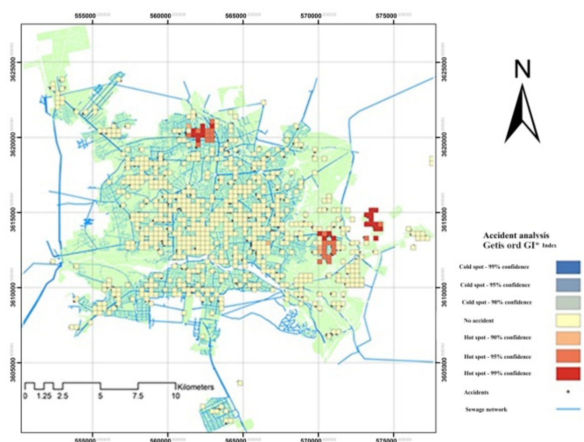

Fig. 2. The hot spots map of the Isfahan sewage network (2015-2020)

of this study can contribute to the predictive analysis in the study area.

In the present study, the factors effective on the occurrence of accidents in the sewage network were divided into the following classes, in order of priority: 1- Improper execution, 2- Network age, 3- Undesirable operation, and 4- Human factors.

Fig. 3 shows the comparative raster map between Getis-Ord Gi* and DRASTIC model at the first class (class A).

As can be seen in the comparative raster map of the first class in Fig. 3, the distribution of the network events in the centre, east and southeast of the city showed a significant correlation between the two indicators of Getis-Ord Gi* and drastic. Soil salt increased pipe corrosion, leading to more accidents. In the southwest of the city, due to the calcareous nature of the soil, there was a greater tendency for accidents to occur and both showed the same result.

As can be seen in the central part of the city, due to wear and long life of pipes, as well as increased vehicle traffic, the number of accidents in the urban sewage network was higher and, in the east, and southwest of the study area, significant correlation with soil salinity was shown.

Fig. 4 shows the comparative raster map between Getis-Ord Gi* and DRASTIC model at the second class (class B).

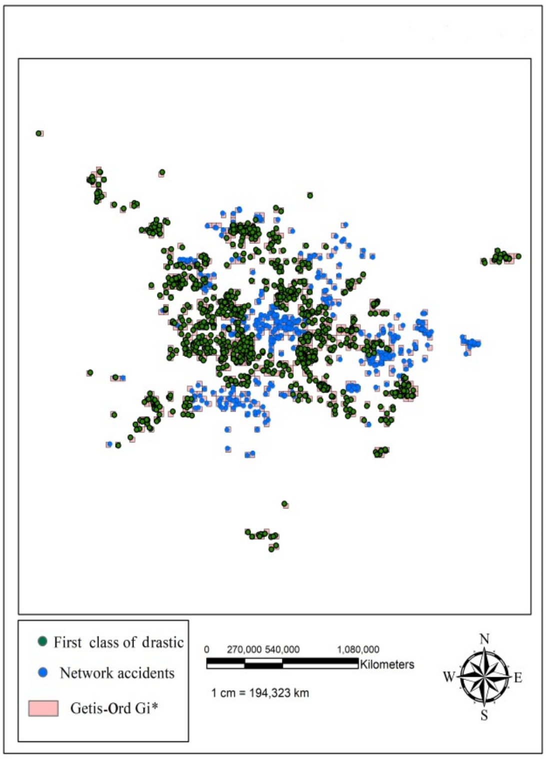

Fig. 3. First class comparative raster map of the sewage network in the study area (class A)

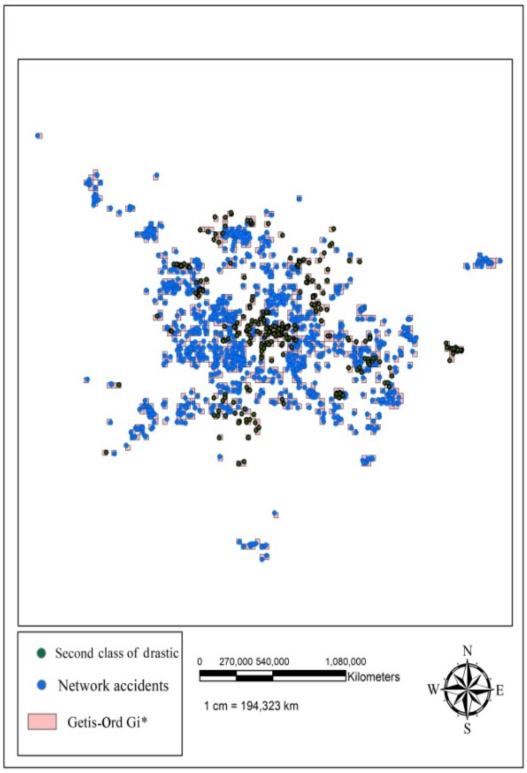

Fig. 4. Second class comparative raster map of the sewage network in the study area (class B)

As can be seen in the comparative raster map of the second class in Fig. 4, the distribution of network incidents in the western part of the city showed a significant correlation between the Getis-Ord Gi* index and the drastic model. In the west, the study area sewage can be one of the causes of accidents, showing the same result by both indicators as both had the maximum values.

Fig. 5 shows the comparative raster map between Getis-Ord Gi* and DRASTIC model at the third class (class C).

As can be seen in the output comparative raster map of the above classes in Fig. 6, the distribution of network accidents in the western part of the city showed a significant correlation between Getis-Ord Gi* and drastic indicators. In the west of the study area, due to proximity to the river and increasing vegetation, tree roots penetrated into sewer pipes. This could be regarded as one of the causes of accidents as both indicators led to the same results, with the maximum values.

The results of classifying the DRASTIC model and Getis-Ord Gi* INDEX into 3 classes can be seen in Table 2.

In the next step, the DRASTIC index was divided into three different classes and compared again with Getis-Ord Gi* index classes. This can be seen in Table 2

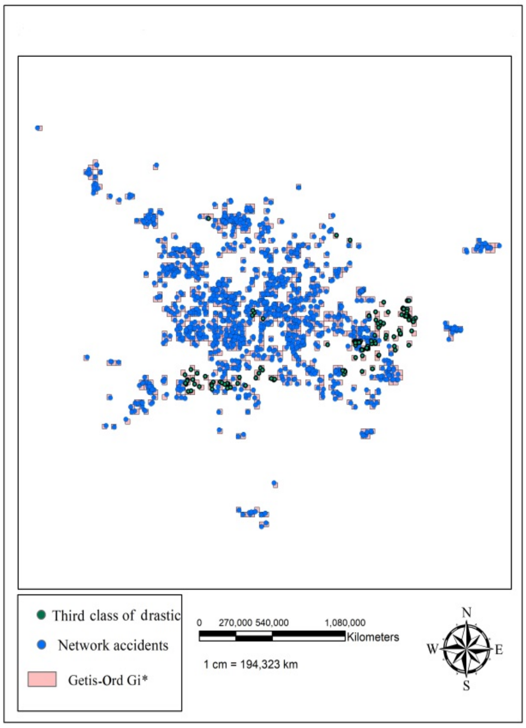

Fig. 5. Third class comparative raster map of the sewage network in the study area (class C)

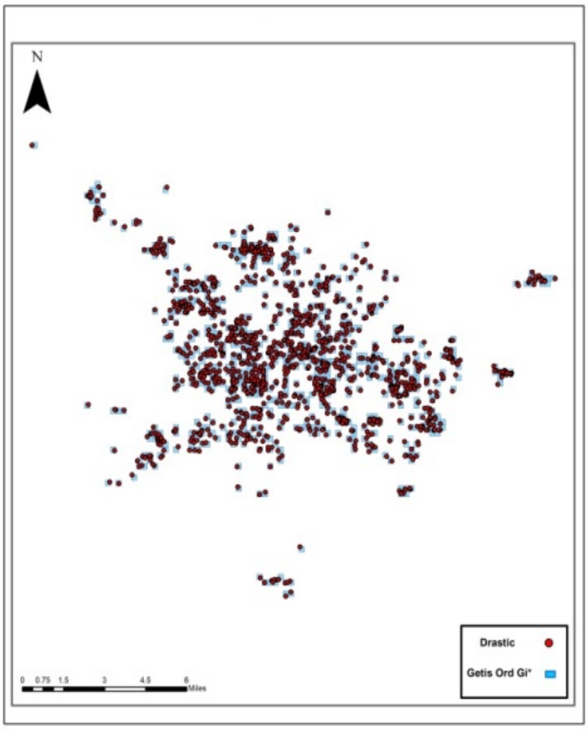

Fig. 6. The comparative raster map between Getis-Ord Gi* and DRASTIC index

Table 2. The results of classifying the DRASTIC index into 3 classes

Index	D1	D2	D3	SUM
G1	358	9	191	558
G2	131	3	48	182
G3	184	6	61	251
G4	204	7	89	300
G5	85	2	92	179
SUM	962	27	481	1470

Table 3. The results of classifying the DRASTIC and Getis-Ord Gi* indices by percentage

Index	D1	D2	D3
G1	37.21	33.33	39.71
G2	13.62	11.11	9.98
G3	19.13	22.22	12.68
G4	21.21	25.93	18.50
G5	8.84	7.41	19.13
SUM	100	100	100

it shows the overlap of the two indicators. The Getis-Ord Gi* index was classified into five classes; the DRASTIC index was divided into three classes.

The results of applying the trial and error method on both indicators showed that the classification of the DRASTIC index into three classes provided more favorable results. Table 3 shows the classification of results of the Getis-Ord Gi* index into 3 classes by percentage.

As can be seen, the Getis-Ord Gi* index was classified into five classes, while the DRASTIC index was divided into three different classes. The probability of an accident was higher in the higher classes and lower in the lower ones. According to the age of the network, the calcareous nature of the soil in the northern part of the study area, and the increased probability of the corrosion of sewer pipes, were more consistent.

If the D1 variable is the minimum value of the DRASTIC index, the D3 variable is the maximum value in the static variable, the G1 variable is the minimum value of the Getis-Ord Gi* index, and the G5 variable is the maximum value of the Getis-Ord Gi* index, it is calculated by dividing the statistical data of the Getis-Ord Gi* index and DRASTIC model classes. It can be seen in Table 4 as the comparative ratios of the indices:

Table 4. Comparative ratios of the indices

Comparative ratio of DRASTIC index	Comparative ratio of the Getis-Ord Gi* index
0.73	0.53
0.68	0.36
1.5	0.32
0	0.42
0	1.08

After that, 2 raster maps can be produced by the two INDICES Getis-Ord Gi* and DRASTIC, the Getis-Ord Gi* and drastic output can be seen in Fig. 7 and 8, respectively. The DRASTIC index in this map is divided into three classes and the Getis index into five. As can be seen, the distribution of accidents in the two raster maps showed a significant similarity.

Table 5 shows the comparison of the maximum, minimum and medium values of the DRASTIC model and Getis-Ord Gi* index. As can be seen, the difference between the maximum and minimum values of the drastic model at the points where the Getis-Ord Gi* index was maximum was only seven units and four units, respectively.

Also, the difference between the minimum and maximum values of the DRASTIC index in those places where the Getis-Ord Gi* index was minimum was 167 and 30 units, respectively.

The difference between the sum of the maximum and minimum values of the DRASTIC index was equal to 1470 and 500 units. Also, the difference between the mean values of the DRASTIC index in the points where the Getis-Ord Gi* index had an average value between 9 and 27 units.

Table shows the comparison of the maximum, minimum and medium values of the DRASTIC model and the Getis-Ord Gi* index by percentage. As can be seen, the difference between the maximum and minimum values of the drastic index at the points where the Getis-Ord Gi* index was maximum was only 3 percent.

In the next step, the values of DRASTIC and Getis-Ord Gi* indices were expressed as a percentage; it turned out that at the maximum point of Getis value, there was only a ten percent difference between the values of the minimum and maximum values of the correct indices, as can be seen in Table 5.

Based on the wight of the effective parameters, some reasons can be considered for the sewage accident in the study area by the geographical situations. It can be seen in Table 6.

Therefore, there was a proportionality of the values in two indices. This means that wherever the index in the stick had a higher value, the Getis-Ord Gi* index was

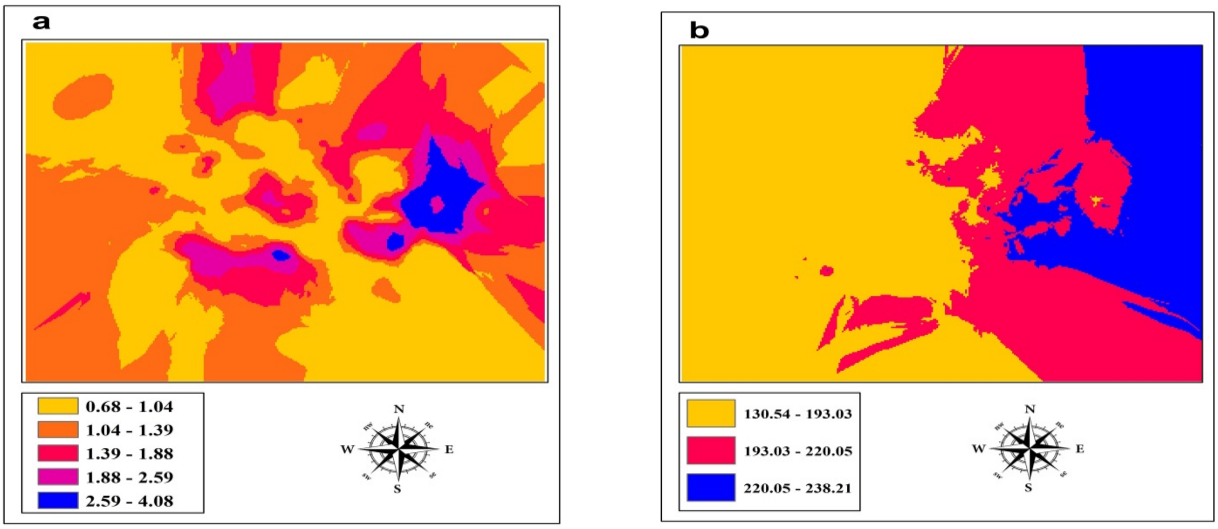

Fig. 7. a) Getis-Ord Gi* and b) drastic indices output

Table 5. Comparison of the maximum, minimum and medium values of the indices

Index	DRASTIC index (minimum)	DRASTIC index (medium)	DRASTIC index (maximum)	SUM
G1 (min)	358	9	191	558
G2	131	3	48	182
G3	184	6	61	251
G4	204	7	89	300
G5 (max)	85	2	92	179
SUM	962	27	481	1470

Table 6. The final weight assessment results of the accidents in the study area

Geographic situation	Accident reason
Central part	Network antiquity, salts of the soil, wrong depth of pipe Lack of valves levelling, increased population and insufficient diameter of pipes, passage of heavy vehicles
Northern part	Network age, population growth, insufficient pipe diameter
Western part	Network antiquity Network age, high soil solutes, insufficient pipe diameter
Eastern part	Salts of the soil, wrong depth of pipe Calcareous soil, population increase and insufficient pipe diameter

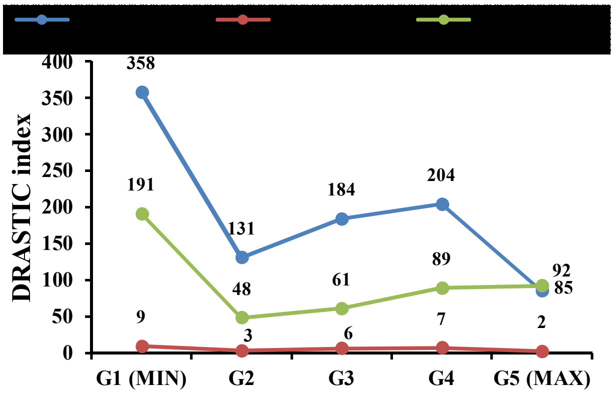

Fig. 8. A two-digit chart comparing the DRASTIC model and Getis-Ord Gi* index

also slightly different; as a result, the probability of accidents in the municipal sewage network would be higher.

As can be seen in the diagram of Fig. 8, the maximum value of the index on the stick is blue and the maximum value on the index is green. The average value for this index is shown in red, indicating that this index does not have an average value; so, this could show absolute accident-prone or accident-free points.

There was no accident point in the points where the drastic model value was half, and the GETIS index was proportional to it. A two-digit comparison chart for this contrast can be seen in Fig. 8.

Table 6 shows the results of events evaluation in different spatial locations of the study area for different spatial locations of it. According to the combination of the Getis-Ord Gi* geographical model and the DRASTIC environmental model, the factors influencing the occurrence of accidents in the study area were estimated and classified as follows:

Also, there are some similar researches using the other models to assess the environmental pollutions. In another paper by Ewuci et al. the vulnerability zones characterized by "Very High", "High" and "Moderate" classes could be located in the eastern and western flanks, and the northwest tip of KMA. These classes are more susceptible to groundwater contamination because of the high draining capability of sand, which is the weathering product of the granites (Ewuci et al., 2016).

In another study by Katiraei et al. the predictive spatial model for the accidents of urban sewage networks was combined with the AHP model in Isfahan. That model was used only in the cultural heritage for Isfahan's ancient monuments drummed from moisture and not destroyed early. However, in the present research, the spatial model was combined with an environmental one (Katiraei et al., 2021).

In a similar paper by Bhuvaneswaran and Gonesh, areas with high water tables were found to be vulnerable because pollutants had short distances to travel before contacting the groundwater. So, the deeper ground water level was low vulnerable and the rating value was smaller; it was also observed that there was a moderate level of groundwater in most parts of the study area (Bhuvaneswaran and Ganesh, 2019).

Al-Abadi et al. also showed that to protect groundwater reserves from contamination, a protective measure should be adopted before exploiting the aquifer for comprehensive agricultural activities in the area. The use of biological methods is preferred instead of pesticides to protect groundwater, especially in the moderate class of vulnerability (Al-Abadi et al., 2017).

Singha et al. showed an increasing trend in DVI scores from the western to eastern part of the Korba district (Singha et al., 2019).

Iqbal et al. also demonstrated the development and application of the fuzzy pattern recognition technique for groundwater vulnerability assessment of the Ranchi district. The vulnerability indices of the Ranchi district were classified into five classes. Both the original DRASTIC method and the proposed fuzzy pattern recognition method were applied to a real-world case study setting; then the results were compared and analysed (Iqbal et al., 2015).

Venkatesan et al. used the spatial analyst tools of GIS environment to determine the DRASTIC vulnerability index by incorporating all thematic layers and reclassifying them by assigning appropriate ratings and weights. The major contribution parameter, depth-to-water table level, was calculated from the observation wells (Venkatesan et al., 2019).

The purpose of this study was to design a spatial model to evaluate the accidents of urban sewage networks in the historical context of cities. Location-based analysis is a powerful tool for the better utilization of urban utility networks (Venkatesan et al., 2019).

In the study conducted by Jozikhamseloee and Taghvaei it was the part where most historical monuments of Isfahan were located (Jozikhamseloee and Taghvaei, 2019).

However, in the present study, the same land uses in relation to urban utility networks and related accidents were analysed and evaluated. In a certain study, only a number of accidents related to sewage network clogging in 2015 and 2016 were studied and sewage network was not addressed. In the present study, all types of sewage network accidents, including network clogging and collapse, were evaluated over a five-year period.

In the study of Mohammadi et al. by performing spatial analysis on urban wastewater network accidents was done only through statistical methods and the result was contrary to the present study related to the concentration of accident-prone areas in the central neighbourhoods and old areas of the city (Mohammadi et al., 2018).

In the study by Rezaei Nodeh et al. the risk of gas transmission lines as another vital artery of cities was studied and the possibility of risk for each part of the pipes was investigated separately, which was shown to be less. However, due to the geographical infrastructure of the mentioned method, the results of the present study can also be generalized to other incidents of urban utility networks such as gas, electricity, telecommunications, etc., (Rezaei Nodeh et al., 2019).

Due to the smaller number of accidents in the gas network compared to the sewage network was a good solution. Due to the multiplicity of pipes in networks such as sewage, this possibility is less feasible in such networks.

In the study done by Javid et al., a management model using GIS was presented for the management of accidents and incidents in urban water distribution networks; according to the research area, which included the water distribution network, the issues of saving and pressure were also considered. By combining this method with the present research method, like the present research, this model could be effective in reducing accidents related to the urban water network (Javid et al., 2010).

According to the mentioned research area, which included the water distribution network, the issues of saving and pressure were also considered. By combining the mentioned method with the present research method, like the present research, this model can be effective in reducing accidents in the urban water network.

The advantages and disadvantages of Drastic model are as follows:

1. It is relatively cheap.
2. The required input data is easily obtained from different organizations and can be implemented in GIS.
3. The results of this model are easily interpreted and decision-making processes are combined.
4. Drastic is an index and overlap model that is designed to generate vulnerability scores for different points by combining several thematic layers.

The most important weakness of this model is that it does not provide an absolute amount of vulnerability. Rather, only areas with high vulnerability and areas with low vulnerability are distinguished from each other. (Bhuvaneswaran and Ganesh, 2019).

5. The Drastic method, like other vulnerability ranking methods, does not provide accurate and absolute results of the vulnerability and distinguishes only high and low vulnerability areas; and shows a relative estimate of the amount of pollution (Ghanbari et al., 2020).

By performing statistical analysis and integration of the results obtained from SPSS statistical analysis software and ArcGIS 10.3 software, the trend of sewage accidents based on the diameter and life of sewer network pipes was investigated. In this study, Kendall and Spearman & Spearman tests were used.

A-Investigate the relationship between accidents and pipe diameters.

Based on the data related to the number of accidents per pipeline, the relationship between the diameter of the pipes and the number of accidents is shown as Eq. (4)

$$Y = -0.0275x + 22.44 \quad (4)$$

Based on the statistical tests performed according to Table 7, it is determined that the diameters of the pipes and the accidents are inversely proportional to each other.

B- Investigating the relationship between accidents and pipe life.

In the study area, the relationship between the number of accidents and the life of pipes, based on data related to the history of accidents, in the age range of 40 years, in the study area is shown as Eq. (5)

$$Y = 0.0225x^2 - 1.0423x + 20.791 \quad (5)$$

Table 8 shows the results of statistical tests. The statistical test shows a direct relationship between the life of pipes and the number of accidents.

 dx.doi.org/10.22093/wwj.2021.300889.3171

Table 7. Results of statistical tests to determine the relationship between pipe life and accidents in Isfahan, (2015-2020)

Statistical test	Diameter	Correlation parameters	Factors	Accident
Kendal	1	The correlation coefficient	Diameter	**-0.905**
	0.004	Significant amount		**0.004**
	7	Number		**7**
Kendal	-0.905	The correlation coefficient	Number of accidents	**1**
	0.004	Significant amount		**0.004**
	7	Number of samples		**7**

Table 8. Results of statistical tests to determine the relationship between pipe life and accidents in Isfahan, (2015-2020)

Statistical test	Pipe life	Correlation parameters	Factors	Accident
Kendal				0.8
	1	The correlation coefficient	Pipe life	0.05
				5
	0.05	Significant amount	Number of accidents	1
	5	Number	Number of	5
Spearman				5
	1	The correlation coefficient	Pipe life	0.9
				0.037
	0.037	Significant amount	Number of accidents	5
	5	Number of samples	Number	5

4. Conclusion

In general, the most important result of this evaluation was providing a new perspective on how the sewage network accidents occur in cities based on an expert's attitude in the sewage network accident sector, thus saving cost and time. Accuracy and speed of access information, ease of updating information, the enhanced ability to deal with unpredictable accidents and ease of the operation of urban utility networks, especially municipal sewage network, can be regarded as different applications of this model. History of urban sewage network events in the historical context of the city are effective factors in the occurrence of these accidents, showing in which areas the probability of the occurrence of sewage network accidents could be higher and what factors might affect the occurrence of these accidents. Considering these two factors makes it possible to predict accidents in such areas in the future. Thus, those areas of the city that have conditions similar to those of places with a history of accidents are naturally more likely to have accidents. This is one of the advantages of this model. It can also be extended to other cities with sewage network and other areas. Determining the appropriate method to change the situation or minimize events in the critical points of the network is a solution that, after designing this model, allows us to know in which areas and why the accidents might occur; then by extending it to the surrounding areas with similar conditions, future sewage accidents could be prevented.

Regarding improper implementation, the use of pipes with poor quality, improper bedding, improper diameter and depth of the pipe, improper designs and soil types were of special importance. As for the age of the network, by dividing the life of the sewage network into four groups, it was found that those areas where the pipes were older and could be classified in groups of 20 to 30 years or more, accidents were more likely to occur. Regarding improper operation, the lack of valves levelling, especially in the north of the study area, could be considered as the most important factor in the occurrence of the accident; this is because with the trapping of the H_2S gas, the possibility of the corrosion of the pipes is increased.

This model has three important features.

1- This model is an empirical model. It means that any time, by updating the information of the accidents records and adding a new incident database to it, it is possible to update the model.

2- The mentioned model has the ability to be generalized to all areas with sewage networks dealing with the problem of network accidents.

3- This model can be generalized to other vital arteries and networks of urban facilities such as water, gas, electricity, etc.

Two important results were obtained regarding the wastewater network pipes in relation to accidents.

A. The less the pipe diameter, the higher accident probability. The reason is the rise of residential complexes and the subsequent population increase.

B. Aging wastewater pipes increase the accidents because of the pipes erosion (Katiraei et al., 2021).

As shown, combining spatial and environmental models produces a qualified model in urban network operations which can be used in various fields, particularly to predict the accidents and environmental risks in all cities with sewage networks and also, the other urban facilities.

In regard to the improper implementation of municipal sewage networks, the use of pipes with poor quality, improper bedding, inappropriate diameter and depth of pipes, improper design and soil type were of special importance. Regarding the age of the network, by dividing the life of the sewage network into four groups, it was found that those areas where the pipes were older and could be classified into groups of 20 to 30 years or more, accidents were more likely to happen. As for unfavourable operations, the lack of valves levelling, especially in the north of the study area, could be considered as the most important factor in the occurrence of the accident; this is because with the capture of the H_2S gas, the possibility of pipe corrosion is increased. By predicting the possibility of dampness in urban historical monuments due to accidents and obtaining useful and promising results, it is possible to expand and generalize the model to areas with a historically high value; due to the special importance of Isfahan in terms of cultural heritage, such a database seems to be a necessity. Regular spacing of the network data collection of surface water and municipal sewage and network specifications, as well as records and reports of the previous incidents, especially around historical buildings, also seems to be necessary.

The following measures should be adopted to prevent the occurrence of accidents in the urban sewage network:

1- Compiling a regular database related to the history of dampness and humidity in the historical places.

2- Updating geographical models related to cultural heritage in the historical contexts of cities in order to help urban organizations to manage the damage and ownership of such buildings.

3- Developing the culture to prevent the destruction that may occur due to the human factors.

4- Using sensors, and fixed and mobile cameras and leak detectors in the municipal water and sewage networks to monitor and evaluate the condition of network pipes, especially around and old regions.

5- Applying suitable bedding when implementing water and sewage network pipes.

6- Properly designing water and sweage network pipes with an appropriate diameter and depth.

7- Repairing water and sewage networks in the areas with old and worn networks and around the old regions and historical monuments.

8- Using long-lasting pipes such as clay and polyethylene pipes, especially around old regions and historical monuments.

9- Creating integrated urban management through Spatial Data Infrastructure[1] and communication between organizations related to urban facility networks, environment and the cultural heritage organizations.

This model is, therefore, suitable for all specialists in urban areas and vital arteries, as well as employees in the field of urban facilities and environment. These people can use this model in short- and long-term planning as a suitable model for predicting and assessing risks, thus leading to the environmental use of urban sewage network accidents based on a spatial approach. Despite the importance of the issue of urban sewerage network accidents, the output of this model has not been presented in the country's water and sewage engineering companies. In the future, it can be used in the country's water and sewerage companies as a way to reduce sewerage network accidents and predict the likelihood of such accidents in the future.

5. Acknowledgement

I would like to thank my distinguished professors for helping me with this article, I appreciate their valuable guidance. Also, thanks goes to Isfahan Water and Wastewater Company for the historical data of urban sewage network accidents of Isfahan in the last five years.

[1] Spatial Data Infrastructure (SDI)

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