Estimation of methane emission from the risers of urban gas network in the metropolis of Mashhad and evaluation of its economic and environmental effects

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Abstract

Background: It is evident that leakage through pipelines, especially in areas where environmentally sensitive can cause many threats to the creatures that live on the earth. Methane gas has a relatively stronger effect on global warming than carbon dioxide thus the identification and prevention of long-term leaks is also of particular importance. Therefore, the current study was designed to estimate methane gas leaks from Mashhad gas risers and investigate the environmental and economic impacts.

Methods: This study was conducted in the form of cross-sectional and aiming analytical-descriptive in all 8 town gas zones of Mashhad (2021). The total stages of this study include: 1) computing the numbers of town gas risers of Mashhad and their ground variables (longevity of risers, service and user type of riser, urban zones, and etc.). 2) Computing the number of risers which have leakage. 3) Determining the sample size and method of sampling. 4) Checking the relationship between leakage and equipment/risers' connections. 5) Estimating the relationship between the service life of the riser and leakage. 6) Determining the relationship between leakage rate and service type of riser (household, industrial and commercial). 7) The relationship between leakage rate and urban zones. 8) Determining the leak rate of the riser in different seasons. 9) Calculating the rate of the economic cost caused by methane leak. 10) Evaluating the environmental aspects of the gas leak.

Results: There was no significant difference between the riser type and leakage rate. However, there was a significant difference between the leakage rate of the riser and urban zones, leakage rate and season, and leakage rate and service life of the riser. According to the US Environmental Protection Agency (EPA), one molecule of methane will increase heating by 28 to 36 times more than one molecule of carbon dioxide over a period of 100 years. Another effect of global warming that can have an adverse effect is to increase the water requirement of plants. By realizing the fact that the service life of the riser, urban zones, and season directly affects methane gas leak, thus a significant amount of gas leakage can be prevented widely by controlling the above items: which demonstrate its effects on the environmental and economic aspects over a long time. Other hands, the direct Methane's effect is global warming and the most important indirect effects include economic, social, cultural and climate changes, extinction of animal species, and human diseases.

Background

According to the statistics, Iran has the second largest natural gas reserves in the world. Although the population of Iran is less than 19% of EU countries and 6% of China, but natural gas consumption in Iran is equivalent to gas consumption in China and the total consumption of EU countries as well. About 214 billion cubic meters of natural gas are consumed in Iran annually. Almost 651 billion cubic meters of natural gas are consumed by Americans every year and this is expected to increase up to 974 billion cubic meters by 2020 [1]. Annual US gas consumption has increased up to 30% from 481.39 billion cubic meter to 628.63 billion cubic meter during 15 years from 1987 to 2001. The average global consumption

of natural gas has been continuously increased by 1.8% annually in the last 8 years which is considered as the fastest-growing energy source [2].

Gas consumption amount has significantly augmented by considering some parameters such as prominent population growth, industrial development in various domains, and efforts to fulfill the existing needs. On the other hand, concerning the evaluation of gas development indicators in different parts of the country, the expansion speed of the main and secondary gas networks has been increasing rapidly in recent years in Iran. Thus, assuring and removing the existing defects in each stage of gas transmission in the gas distribution network to prevent gas leaks and the environmental and economic hazards caused by it, is necessary and undeniable [3, 4]. The expansion of urban residential areas towards refineries, the development of these industries, and the increase in the number of working people in these industries also lead to an increase in the number and severity of the accidents and leave drastic and irrecoverable damages [5].

Some factors involved in gas loss (gas imported into gas distribution network and gas consumed by consumers) are as follows: gas leak from pipes and fittings (less than 10%), gas theft, measurement errors, third-party damages, and illegal exploitation [6, 7]. Permeation and emission of flammable and toxic hazardous substances in chemical and process industries are always one of the hazards which threaten the lives of people working there, of the residents around these industries, and also the environment [8]. Natural gas leakage and diffusion from transmission and distribution networks, in addition to the environmental consequences like increase in the process of global warming, also leads to the safety hazards in the centers of population as well as the health outcomes for the residents of these areas. Overall, some consequences of natural gas leakage are environmental pollution, a decline in health index in humans and other organisms, explosion hazards, natural gas loss, environmental recovery fees, repairing and replacing costs of buildings equipment, waste of time, and possible statutory offenses: therefore, the sufficient motivation to solve such a problem is provided by the three factors of economy, safety and environmental considerations [9].

In recent years, one of the most important challenges of sustainable development is the wide set of quick processes like changes in demographic profile, economic and social dynamics changes, technological advancement, and declining environmental trends. Therefore, it is necessary to have a better understanding of the relationship between these trends and the related changes in the environmental, social, and economic conditions. Due to the position and necessity of the sustainability of development and the different economic systems experiences in this field that tend to neglect the role of the environment, the importance of political guidance to consider the interactions between the economy and the environment along the sustainable development is evident [10].

Today, one of the most pivotal issues in protecting the environment is to find some ways to remove various types of pollutants from the environment. Some of these pollutants include heavy metals, chemical pollutants, and particularly gases and household gases: gases release into the environmental resources through different ways such as industrial, household, commercial, and a small percentage of

agricultural ways and unbalance the material cycles in natural ecosystems and adversely affect the environment [11]. The main reason for global warming in the last 50 years has been due to the carbon dioxide and methane emissions caused by human activities; however, the per capita greenhouse gas emissions rate in developed countries is 2 to 4 times higher than the required amount for the stability of greenhouse gases in the atmosphere. The ecological footprint in these countries is also 4 to 9 times more than the biological capacity of the earth [10]. The global ranking of Iran in terms of the Environmental Performance Index (EPI) among 132 countries in 2012 with a 61-step decline just during 6 years has been announced 114. Although the ranking of Iran improved slightly in 2015 and was ranked 105th, even it showed an unfavorable performance compared to the countries of the region [12,13].

Leakage through pipelines, especially in areas where are environmentally sensitive can cause many threats to the creatures that live on earth. Methane gas has a relatively stronger effect on global warming than carbon dioxide thus the identification and prevention of long-term leaks is also of particular importance. Furthermore, the leak in the town gas network, due to the loss of some part of valuable materials which are among the products or raw materials, also leads to economic losses [8,14]. Therefore, the current study was designed to estimate methane gas leaks from Mashhad town gas risers and investigate the environmental and economic impacts to satisfy the following purposes:

- Selecting the statistical population of Mashhad town gas risers;
- Identifying the risers having leakage in the statistical population;
- Evaluating the relationship between the ground variables and their leak rate;
- Examining the environmental – economic aspects.

Methods

2-1- Study Design

The present study was conducted in the form of cross-sectional and aiming analytical-descriptive with the title of “Estimation of methane gas emission from urban gas network and assessment of its economic and environmental effects in the GIS platform” in all 8 town gas zones of Mashhad city (2021). The total stages of this study include: 1) computing the numbers of town gas risers of Mashhad and their ground variables (longevity of risers, service and user type of riser, urban zones, and etc.). 2) Computing the number of risers which have leakage. 3) Determining the sample size and method of sampling. 4) Checking the relationship between leakage and equipment/risers’ connections. 5) Estimating the relationship between the service life of the riser and leakage. 6) Determining the relationship between leakage rate and service type of riser (household, industrial and commercial). 7) The relationship between leakage rate and urban zones. 8) Determining the leak rate of the riser in different seasons. 9) Calculating the rate of the economic cost caused by methane leak. 10) Evaluating the environmental aspects of the gas leak.

2-2- Computing the numbers of town gas risers of Mashhad

The number of town gas risers was computed using the billing system and technical documentation of Mashhad Gas Company. These statistics were used in the next steps of investigation.

2-3- Identifying the number of risers having leakage

To determine the statistical population from among 350,000 gas risers in Mashhad metropolis, using the office automation system of Mashhad Gas Company, 1% of gas risers were randomly selected.

The leak detection of all risers from the statistical population was performed using the gas detector device GTTM series and their condition in terms of the existence, location, and concentration of gas in the leakage point was determined and recorded. The accurate leakage rate of methane from risers having leakage was obtained based on the Volume/Mass Flow Rate and using gas detector device Hi-Flow Sampler *S.2002*, Made in Haryana/ India, with ISO9001 Certification [15].

The Hi-Flow Sampler is a portable, intrinsically safe, battery-powered instrument designed to determine the rate of gas leakage around various pipe fittings, valve packing, and compressor seals found in natural gas transmission, storage, processing, gas gathering, production, offshore, and distribution facilities. A component's leak rate is measured by sampling at a high flow rate so as to capture all the gas leaking from the component along with a certain amount of surrounding air. By accurately measuring the flow rate of the sampling stream and the natural gas concentration within that stream, the gas leak rate can be calculated using Eq. 1. The instrument automatically compensates for the different specific gravity values of air and natural gas, thus assuring accurate flow rate calculations [16,17].

$$L = F \times \left(C_g - C_b\right) \times 10^{-2} \quad \text{Eq. (1)}$$

Where; L is rate of gas leakage from source (cfm), F is sample flow rate (cfm), C_g is concentration of gas from leak source (%) and C_b is the background gas concentration (%).

2-4- Determining the sample size and method of sampling

The sample size was obtained using Cochran Formula with a significance level of 5%. After determining the sample size, Sampling was implemented in the forms of simple random and classified random [18].

$$n = \frac{Z^2 \times S^2}{d^2} \quad \text{Eq. (2)}$$

Where *n* is the number of final sample size, *Z* is the normal variable value with confidence level α-1, *S* is the standard deviation and *d* is the acceptable level of mistake.

2-5- Checking the relationship between leakage rate and equipment/risers connections

The relationship between the risers having leakage and equipment– risers' connections (elbow fitting, pipe union, coupling, nipple and etc.) was investigated after identifying the risers having leakage. The

data were considered normal since the data of this hypothesis was 2685 cases and Eta test was used for statistical analysis.

2-6- The relationship between leakage rate and urban zones

The relationship between leakage rate and the urban zones (zones 1 to 8) was examined and analyzed. Eta test was used for statistical analysis.

2-7- Calculating the rate of the economic cost caused by a methane leak

Economic costs were investigated from two aspects: 1- Direct costs, 2- Indirect costs.

2-7-1- direct costs

The average price of methane around the world is 15 cents per cubic meters. However, there is a substantial difference in these prices among countries. As a general rule, richer countries have higher prices while poorer countries and the countries that produce and export oil have significantly lower prices. One notable exception is the U.S. which is an economically advanced country but has low gas prices. The differences in prices across countries are due to the various taxes and subsidies for gasoline. All countries have access to the same petroleum prices of international markets but then decide to impose different taxes. As a result, the retail price of methane is different [19].

2-7-2- Indirect costs

Indirect economic aspects were evaluated qualitatively. Accordingly, the researchers collected the information by forming specialized working groups and using the opinions of experts (professors and veterans in the field of industry): The selection criteria for experts were research background and work experiences in the aforementioned domain. Eventually, 10 experts were interviewed. The interview was initiated with 2 experts; this process continued using the snowball method until data saturation was reached [20].

2-8- Evaluating the environmental aspects of the gas leak

The environmental aspects were also evaluated qualitatively and in terms of both direct and indirect aspects. Hence, the researchers collected the information by forming specialized working groups and using the opinions of experts (professors and veterans in the field of industry): The selection criteria for experts were research background and work experiences in the aforementioned domain. Eventually, 10 experts were interviewed. The interview was initiated with 2 experts; this process continued using the snowball method until data saturation was reached [20].

Statistical analysis

Collected data were analyzed by Statistical Package for the Social Sciences (SPSS) V.26 (SPSS Inc., Chicago, IL, USA) using statistical tests such as Eta, Pearson, Cramer’s V. The statistical significance level

was set at $P < 0.05$ [21].

Results

In this section, the number of risers in Mashhad, the leakage rate of each riser, the relationship between component leakage with different variables and their direct and indirect effects are mentioned. Figure 1 shows the each part of riser.

3-1- Computing the numbers of town gas risers of Mashhad

Figure 2 shows the location of town gas risers. The number of town gas risers was obtained 350000 using billing system and technical documentation of Razavi Khorasan Gas Company.

3-2- Computing the number of risers having leakage

The number of risers having leakage which were measured their leakage by using *the Hi-Flow Sampler* instrument was obtained 574 (about 17.5%).

3-3- sample size

The statistical sample size was obtained at 3251 according to the Cochran Formula and with a significance level of 5%.

3-4- The relationship between leakage and equipment/ risers' connections

The result of Eta test has been provided in Table 1. The result of this test indicates that there is a significant difference between the average of leakage and different leakage locations at a 95% confidence level.

Table 1
The comparison of average leakage at different leak locations

	Average leakage (Liter Per Minute (LPM))	Numbers	Std. deviation
Regulator body	0.7	7	1.68226
High pressure shutoff valve	0.4583	542	1.25707
Low pressure shutoff valve	0.2531	369	1.00293
thread before the locking valve	0.25	6	0.20736
Regulator vent	0.2014	219	1.07812
Coupling	0.1589	370	0.67706
Regulator bottom thread	0.15	6	0.32094
Three-way	0.1459	98	0.82088
Nipple	0.1276	87	0.43232
Pipe union	0.1271	724	0.58042
Locking valve body	0.0849	192	0.43067
Elbow fittings	0.0359	64	0.12894
Average/ Total	0.2244	2684	0.7182

The average leakage amount at different locations has been also indicated in Fig. 3. The maximum amount of leakage is seen in the regulator body and then in high-pressure shutoff valve. The minimum amount of leakage is seen in the thread on top of the regulator. No leakage has been recorded in the thread on top of the regulator.

3-5- The relationship between the leakage rate and urban zones

The relationship between the leakage rate and Mashhad urban zones has been shown in Table 2. The mean LPM is arranged in descending order of the recorded mean and shows that zone 2 (with a mean LPM of 0.26), zone 5 (with a mean LPM of 0.23) and zone 3 (with a mean LPM of 0.21) have the highest mean LPM and zone 4 (with a mean LPM of 0.10) and zone 6 (with a mean LPM of 0.11) had the lowest mean LPM.

Table 2
Relationship between leakage of riser and urban zones

	Mean LPM	N	Std. Deviation
Zone 2	0.2649	618	1.03624
Zone 5	0.2316	421	0.98801
Zone 3	0.2181	441	0.79837
Zone 7	0.1506	559	0.73394
Zone 8	0.1295	210	0.59607
Zone 1	0.1277	224	0.37217
Zone 6	0.1197	573	0.70598
Zone 4	0.1073	205	0.45352
total	0.1809	3251	0.80321

3-6- Economic costs

3-6-1- Direct costs

According to the calculation of the total leakage rate from Raisers that had leakage in the statistical population and the calculation of per capita leakage in the statistical population, the average leakage rate was calculated as 0.185 liters per minute. Due to the presence of about 350,000 raisers in the metropolis of Mashhad, the total leakage rate in this city was estimated at 33,000,000M^3/Y (64,000LPM or 3,800 m^3/hr). Considering the normal price per cubic meter of methane gas is 15 cents, for this leakage rate of natural gas, the annual cost of the gas leak was calculated as 5000000$.

3-6-2- Indirect costs

Indirect costs were evaluated from different aspects that the most important of which are briefly mentioned as below:

- The effects of methane emission on global warming are about 28 times that of carbon dioxide, which due to this fact and significant methane leakage in urban gas raisers in the metropolis of Mashhad, this is equivalent to more than 600 KT of carbon dioxide emission. With an average world price of 50$ per ton of CO2, the indirect cost of methane leakage would be more than 30 million $.

3-7- Environmental aspects

Determining environmental impacts is possible through environmental monitoring; which is the regular review and determination of indicators of the components that are affected. Methane decays in the

atmosphere faster than carbon dioxide, but methane is a much stronger greenhouse gas than carbon dioxide. According to the US Environmental Protection Agency (EPA), one molecule of methane will increase heating by 28 to 36 times more than one molecule of carbon dioxide over a period of 100 years. Recent data show that the concentration of methane in the atmosphere has increased from about 1775 part per billion in 2006 to 1850 part per billion in 2017.

In 2018, methane, about 60 percent of which is man-made, reached atmospheric concentrations two and a half times higher than pre-industrial levels. Although the amount of carbon dioxide in the atmosphere is much higher, methane has 84 times the warming power of the climate system in the first 20 years after release [22]. Another effect of global warming that can have an adverse effect is to increase the water requirement of plants, which has been studied. It is expected that with increasing temperature, the evaporating power of air or the evapotranspiration potential of the reference surface (ET0) will increase and as a result, the water requirement of plants will increase. Considering that ET0 is the most important parameter in irrigation and drainage calculations and plays a role in the design and capacity of irrigation systems, the effects of global warming on it and consequently on agricultural water consumption should be investigated [23].

Climate change is a global phenomenon of climate change that is caused by changes in the Earth's normal climatic conditions (in terms of temperature, precipitation and wind), especially as a result of human activities. As a result of the Earth's climate imbalance, the stability of the planet's ecosystems, as well as the future of humanity and the stability of the global economy, are threatened. This is a wide range of global phenomena created mainly by the burning of fossil fuels that add heat-trapping gases to the Earth's atmosphere. These phenomena include rising temperatures, which are characterized by global warming, but also include changes such as rising sea levels, loss of ice in Greenland, Antarctica, the North Pole, and mountain glaciers throughout the world is changing flowers/ plants and severe weather events. Hence, climate change refers to global warming and its side effects [24,25].

At the beginning of the twentieth century, world temperatures were almost constant, and after the expansion of world industrialization, world temperatures have risen. Baseline temperature to compare the current air temperature, the air temperature before the industrial revolution is called pre-industrial levels [24,25].

Storms, floods, droughts, and severe forest fires all indicate unusual high-velocity changes in the Earth's atmosphere. Climate change and global warming have become one of the most important environmental challenges today, affecting all countries in the world, including Iran, and tackling these changes requires global action. Climate change can make it difficult and impossible to predict climate patterns, and these unexpected climate patterns can make it difficult to maintain and grow crops in agriculturally dependent areas because they can no longer meet the expected temperature and rate. Rain trusted [26,27]. The cause of current climate change is mainly human activities such as burning fossil fuels, such as natural gas, oil and coal, which emit greenhouse gases into the Earth's atmosphere. These gases trap the heat of

the sun's rays inside the atmosphere and increase the average temperature of the earth. This increase in global temperature is called "global warming" [28].

Discussion

This study was conducted to estimate the methane gas leak from Mashhad gas risers and investigate the environmental and economic impacts in GIS platform in 2021. There is a significant difference between the leakage rate and leakage location; the highest leakage rate occurs in the regulator body, high-pressure shutoff valve, and then in low-pressure shutoff valve, respectively. There is a significant difference between the service life of the riser and its leakage rate (P-Value = 0,001). The highest rate of leakage was in the service life range of 10 to 20 years (n = 140). The second rank of the risers leakage belonged to the service life range of 20 to 30 years (n = 124). The lowest amount of leakage of risers is seen among the risers with less than 5 years of service life and being in operation (n = 77). There is no significant difference between the type of the riser and the leakage rate (P-Value = 0.280). On the other hand, there is a significant difference between the leakage rate of the riser and urban zones (P-Value = 0.0001) (Perhaps in the 1 to 8 zones of Mashhad, the cultural differences of the people, the social structure of society, class differences will affect the amount of gas consumption); which this can be due to various reasons such as soil type, old or new equipment in that zones, climate, etc. According to the results found, there is also a significant difference between the leakage rate of the riser and different seasons (P-Value = 0.0001).

A study with the title of “Experimental measuring and predicting the emission factor of methane gas in zone 7 of gas transmission operation” was performed in 2020 by Mohammadi Khorsandy et al. First of all, they examined the operational parameters affecting gas emission rate including ambient temperature, line pressure, blowdown valve type, and the open-closed status of bypass valve before blowdown, internal leakage status of bypass valve before blowdown, valve longevity, leak sounds and concentration of leakage in 10- 10000 ppm limit. Six different patterns were defined based on different input parameters to find parameters affecting emission rate. The results related to the prediction of methane emission factor using neural network indicated that the pattern with input parameters including ambient temperature, line pressure, valve longevity, leakage sounds, and concentration of leakage represents the best results. A correlation coefficient of this pattern was R2 = 0.97853, which was the highest among the patterns [29]. In the current study, there was no significant difference between the riser type and leakage rate; on the other hand, there was a significant difference between the leakage rate of the riser and urban zones (P-Value = 0.0001) and seasons of a year as well (P-Value = 0.0001).

Mechanical and process factors are considered as the most important gas leak in the present study just like the study of Shahedi-Aliabadi. Haghighat et al also conducted a study with the title of “investigating energy efficiency in the household sector of the country’s provinces”. They measured energy efficiency in 28 provinces. Energy consumption was examined using the stochastic frontier method during the years 2002 to 2011. According to the results, energy consumption has very low and high elasticity compared to the price and family per capita income level, respectively and energy consumption will be reduced by increasing the family size. Ilam, Sistan Baluchestan, Ardabil, and Bushehr provinces have the least energy

efficiency in the household sector among the provinces of the country [30]. In the current study, the heavy price of leaked gases was calculated and the results indicated that costs can be saved directly by controlling the cases affecting the leakage.

Unfortunately, these days not many efforts are being made at the global, industrial and governmental level to control the severity of air pollution and the greatest burden of reducing this dilemma is imposed on the citizens. Preventing global warming is one of the most important issues which the world today is at war to counter it and of course, we are observing a set of innovations and experiences aiming to create alternative and unconventional options to reduce pollutants. Air pollution is one of the greatest indications of the wrong lifestyle and is also a challenge we must overcome to build a better tomorrow.

If the world were to be on track to reach the goals of the Paris Agreement on global warming below 2° C, methane levels in the atmosphere would theoretically decrease. Instead, these levels have been rising since 2007 and have risen even faster since 2014. Most scenarios for stabilizing the global average temperature at 2° C above pre-industrial levels depend on strategies to reduce the total amount of carbon dioxide entering the Earth's atmosphere and remove what already exists in the atmosphere through methods such as tree planting. Or underground isolation. Most scenarios for carbon dioxide emissions typically involve hundreds of billions of tons of emissions over decades, yet do not return the atmosphere to pre-industrial levels. In contrast, according to researchers, methane concentrations can be returned to pre-industrial levels by removing about 3.2 billion tons of gas from the atmosphere and converting it to carbon dioxide equivalent to several months of global industrial emissions. If successful, this approach will eliminate almost one-sixth of all global warming to date [22]. Environmental effects are environmental changes in nature that can be favorable or unfavorable. In environmental monitoring, the desired parameters are scored in a checklist to provide appropriate control information according to the final score of the indicators [31].

Conclusion

By realizing this point that service life of the riser, urban zone, and seasons of a year affect methane gas leak directly, hence a significant amount of gas leakage can be prevented widely by controlling the above items: which demonstrate its effects on the environmental and economic aspects over a long time. Also, given that the highest leakage rate of the risers occurs in the range of 10–20 years and 20–30 tears, respectively; and most leaks occur in the regulator body, high-pressure shutoff valve, and then in low-pressure shutoff valve; so, if possible, the regulator body, high-pressure shutoff valve, and low-pressure shutoff valve should be replaced in the risers with the service life of more than 10 years to prevent a significant amount of methane leakage. The direct effect of Environmental pollution (alteration and degradation of animal/plant ecosystems, biological resources, and life cycle).

Declarations

Conflict of interest

The authors declared no conflict of interest.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The data sets used and analyzed in the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Concepts and design: Khosro Ashrafi

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Experimental studies: HamidReza Parastesh

Data analysis and statistical analysis: Mohammad Ali Zahed

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Figures

NAME	No.
Union	1
Coupling	2
Elbow	3
Niple	4
T-Service	5
Reg.Down Stem.Thread	6
Reg.Body	7
L.P.Stem	8
Reg.Vent	9
Reg.Up Stem.Thread	10
Locked Valve Body	11
H.P.Stem	12
Thread before locking valve	13

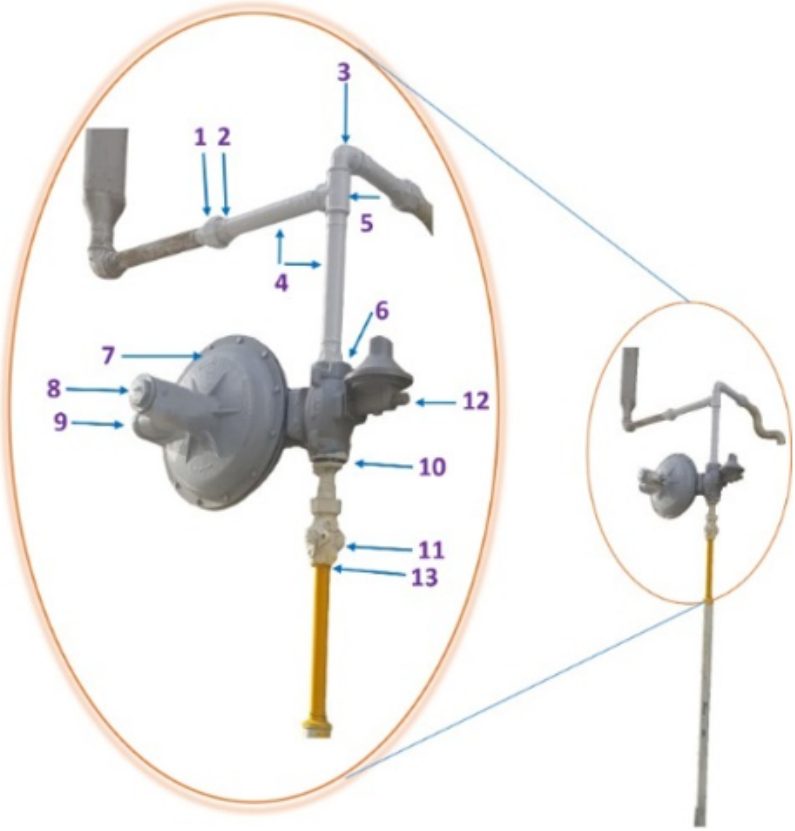

Figure 1

different parts of riser

Figure 2

location map and emission rate map of Statistical Society Mashhad metropolis gas risers

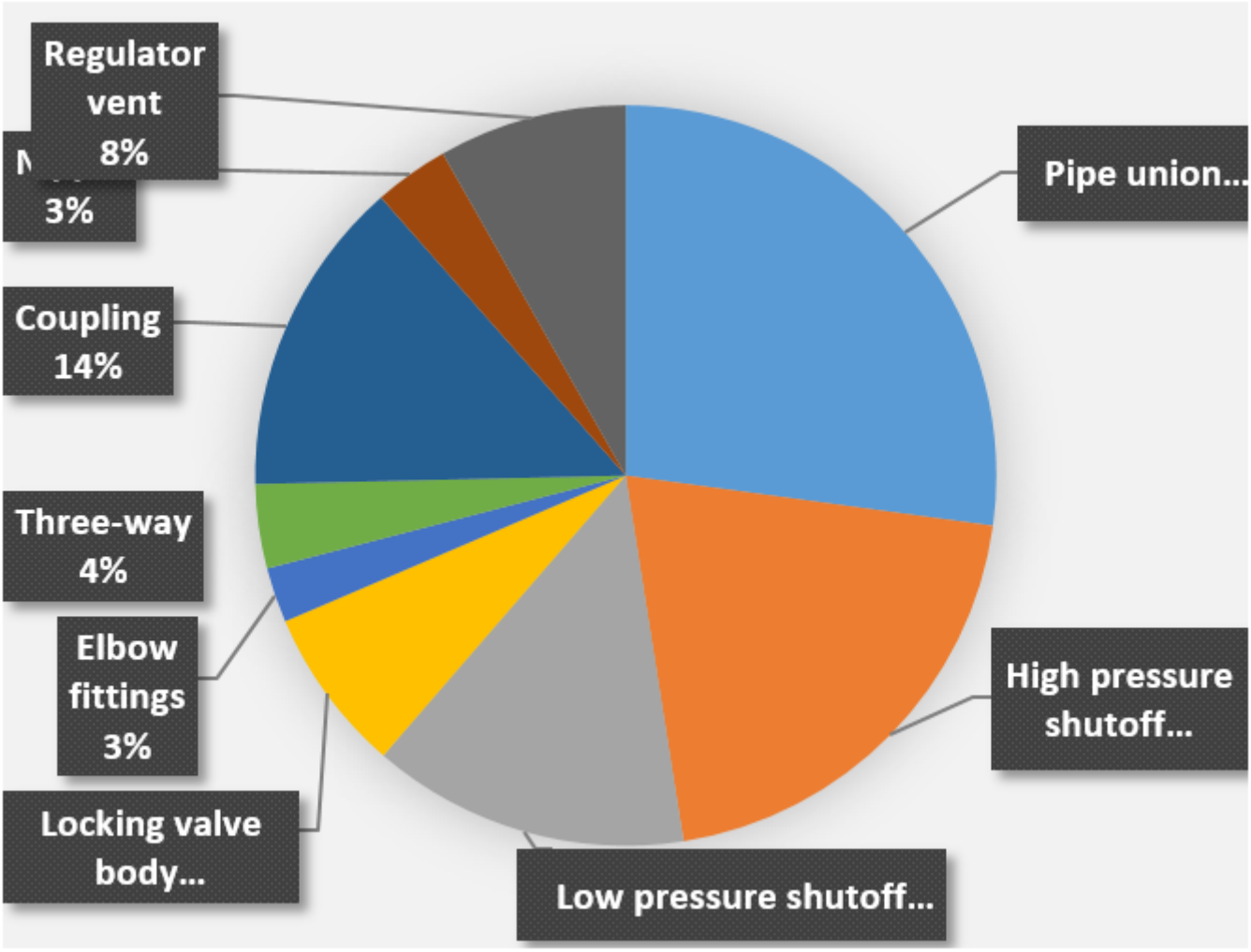

Figure 3

Frequency percentage of registered cases relative to leak location