# Prioritizing potential use of urban treated wastewater using expert-oriented and multi-criteria decision-making approaches: a case study in Iran

Elahe Vaseghi, Mohammad Reza Zare Mehrjerdi, Alireza Nikouei and Hossein Mehrabi Boshrabadi

## ABSTRACT

Allocating effluent of wastewater treatment plants to users of economic sectors and satisfying their requirements has created a challenging debate and a need for prioritization. This study assesses the importance of sectors that utilize treated wastewater (TWW) using risk and social acceptability indexes based on expert-oriented approaches. Considered sectors are agriculture, industry, urban green space and natural resources and the study area is located in Iran, around the Isfahan North Wastewater Treatment Plant. The risk index is calculated using Frank and Morgan model and consequently TWW use in the industrial sector is less dangerous than other sectors. Moreover, the social acceptability index, which was determined using Mamdani fuzzy inference set, indicates higher acceptability of TWW use in natural resources sector compared with other sectors. By constructing the conceptual model, generating the decision matrix and using the results of gray relational analysis decision-making model for the four sectors, the allocation priorities of TWW became industry, natural resource, green space, and agriculture respectively. It is suggested that Water and Wastewater Company grant permission for TWW use to water-consuming industries and man-made forests development, which result in increasing employment, reduction of harmful effects of dust, and water consumption decrease.

**Key words** | gray relational analysis, multi-attribute decision-making, risk, social acceptability, wastewater

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## HIGHLIGHTS

- The steps of Frank and Morgan's technique were formulated to calculate the risk index.
- Use of TWW in the industrial sector has a lower risk than other sectors.
- Use of TWW in the natural resources sector has a higher social acceptability than other sectors.
- Agricultural sector has the lowest allocation priority of TWW use due to the high hazards and low controlling actions.
- Due to social issues and the risks of using TWW, its allocation priorities are the industry, natural resource, green space, and agriculture sectors respectively.

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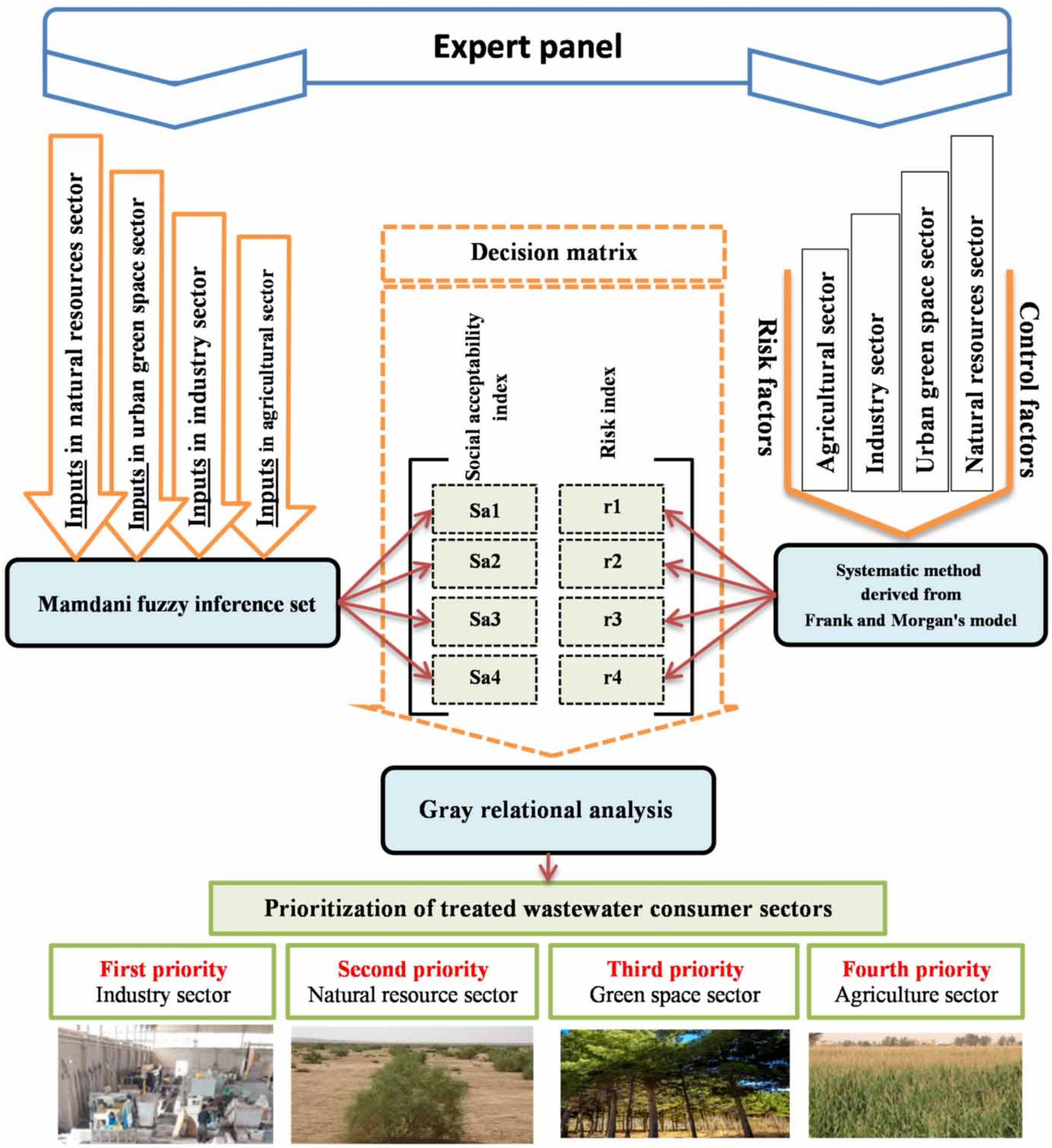
## GRAPHICAL ABSTRACT




## INTRODUCTION

Food, energy, human health, the environment, and protection against water-related diseases, all of which are related to water, are considered opportunities for economic growth and are among essential factors for development. Dependency on water and its insufficiency for different consumption sectors such as urban areas, industries, agriculture, and natural environment has led to the competition among various economic sectors for such a limited resource (WWAP 2012). Thus, due to rapid world population growth and inadequacy of conventional water resources for human needs, water policy-makers and economists seek to find new solutions to supply water through the replacement of new water resources and allocate them optimally among different users. In this regard, use of non-conventional resources, especially treated wastewater (TWW) as a new and permanent resource, has been recognized as an incentive solution to deal with water shortage problem throughout the world (Garcia & Pargament 2015).

Non-conventional water resources are defined as the resources that fail to be used conventionally and their use needs applying special management and protection policies. In general, non-conventional water resources are divided into the three categories of saline water, drainage water and effluent (wastewater – treated or untreated) (Hamdy 2005). The source of wastewater can be urban, industrial, agricultural or a combination of them. Urban wastewater, in general, is 99.9% water and contains only 0.1% solids (Karia & Christian 2013). In terms of physical, chemical, biological, and pollutant properties wastewater has four states: weak, medium, strong, and very strong, which can be treated in treatment plants (Von Sperling 2007). TWW is produced by different sources and is exposed to physical, chemical, and biological treatment for reuse. The most common type of TWW is created by treating urban wastewater (Cirelli *et al.* 2012), which includes human body wastes such as stool and urine and the wastewater related to hygiene activities (such as bathing and washing clothes), cooking, and other water consumption in the kitchen (Metcalf & Eddy 2014). Due to population growth and urban development, water consumption and wastewater production per capita have increased significantly during the recent years. Thus, despite the increasing reduction of water supply from conventional resources, especially in arid and semi-arid areas, the use of TWW as a non-conventional water resource is increasing; hence, its use as a sustainable water resource has become more attractive for water management planners (Baawain *et al.* 2020). Using the effluent of wastewater treatment plants in economic sectors leads to various advantages such as presenting a cheap and permanent water resource, decreasing treatment costs, releasing some high-quality water supply for other consumption, and reducing the environmental effects of effluent discharge in water resources (Reznik *et al.* 2017).

According to previous studies, depending on the wastewater treatment processes and the local culture of people living in any area the TWW can be used for various purposes. These are agricultural use (Cirelli *et al.* 2012; Neji & Turki 2015; Saldías *et al.* 2015), green space irrigation and environment protection (Barbosa *et al.* 2015; Licata *et al.* 2017), and industrial use (Hansen *et al.* 2016).

Notwithstanding the advantages of using TWW, some disadvantages may exist regarding its use in each economic sector as well. Different hazards are observed in using wastewater resources and their high severity risks usually lead to the impossibility of compensating for their outcomes. The results of studies that have recognized and assessed the possible hazards and potential outcomes related to TWW use (Saldías *et al.* 2015; Kibuye *et al.* 2019) and studies that have evaluated the public acceptability of TWW use (Antakyalı *et al.* 2008; Drechsel *et al.* 2015) have shown that reasons such as the lack of suitability between TWW quality and environmental standards, lack of information about the benefits of TWW, fear of its possible health threats, and cultural as well as religious issues have led to low social acceptance of using this input as water in various products.

Thus, the risks of TWW use for water, soil, air, organisms, equipment, and facilities are very important. In this regard, the calculation and comparison of risk index within the sectors demanding the urban TWW is essential before making any decisions about the type of urban TWW use. On the other hand, social acceptability index can help decision makers to rank TWW use among economic sectors because of the difference between the acceptability of water input and TWW input among different sectors. However, most of the previous studies have just paid attention to the feasibility or prioritization of use of urban TWW only in one sector, especially the agriculture sector (Chung & Kim 2014; Neji & Turki 2015). Of course, there are studies that have evaluated the potential for wastewater use in different scenarios according to economic, social, and environmental criteria in several sectors such as agriculture, industry, and green space (Garcia & Pargament 2015; Ramos *et al.* 2019). But to the best of our knowledge, there is no study about prioritizing the allocation of TWW among main users such as industry, agriculture, natural resources, and green space with respect to various indexes including risk and social acceptability. Therefore, considering the importance of risk and social acceptability indexes in wastewater allocation, the main purpose of this study is to calculate and combine these two indexes and prioritize sectors for using the TWW in the study area, which requires a decision-making model.

Expert-oriented models along with multi-criteria decision-making (MCDM) models are used to prioritize policies, actions and alternatives under study based on the nature of the criteria (Bottero *et al.* 2018; Hou &

Triantaphyllou 2019). Thus, the present study applies the expert-oriented model and gray relational analysis (GRA) as one of the MCDM models to prioritize and allocate urban TWW optimally based on minimum risk and maximum social acceptability in Iran. GRA solves the issues of complex relationships among different variables by combining different criteria and determining a new criterion for each alternative. Then, the best alternative is selected by comparing the calculated criterion of different alternatives (Zhu *et al.* 2019). In this study, one of the most important treatment plants in Iran was selected as a case study to apply this model.

Iran is located in an arid and semi-arid region of the world and faces a water shortage crisis and for this reason, it can be expected that internal tensions and conflicts might occur in this country. Replacement of TWW as a new water resource is considered as one of the solutions for decreasing water limitation and challenges (Saatsaz 2019). The last circular related to TWW use is the basis for making decisions on inter-sectorial allocation of TWW in Iran. This circular represents the overall framework of making decisions about how to use TWW by considering the conditions of plains and basins of this country (Water & Wastewater Macro Planning Bureau 2014). Furthermore, based on a report published by the President Deputy Strategic Planning and Control in the Islamic Republic of Iran in 2010, a large amount of TWW exists in all of Iran's basins for which the priority of use should be specified in their utilization management. This prioritization considers Iran's water management structure and scientific principles based on basin divisions by collecting the information of consumption and available water per capita in six basins (Caspian Sea, Persian Gulf, Urmia, central, Hamun and Sarakhs), their changes trend, and the potential index of saline, semi-saline, and non-conventional water resources in each basin. Despite non-negligible differences in the treatment plants of each area, the characteristics of the environment around these plants and the requirements of their covered area are important for determining and prioritizing the type of consumption of each treatment plant's effluent as an alternative resource for supplying water in economic sectors. This report showed that in the categorization of the 30 sub-basins, Gavkhouni sub-basin was ranked first for urban TWW consumption planning. A considerable part of this sub-basin is located in Isfahan province and the central part of Iran. Therefore, in this study, the area covered by the wastewater treatment plant in the north of Isfahan City of Isfahan province of this sub-basin was selected as the study area. Since this is the first study related to the prioritization of the potential use of urban TWW in Iran, it can be used as a guide for decision-making in all regions of the country. In this context, the contribution of this study is to introduce the necessary methodologies for calculating indexes and how to prioritize potential uses of TWW using decision-making models. This process can be fully generalizable to other treatment plants and will facilitate the management of treated wastewater resources in the country.

## STUDY AREA

Isfahan's north wastewater treatment plant with an area of 68 hectares and a capacity of 250,000 cubic meters per day is the largest treatment plant among 23 wastewater treatment plants in Isfahan province. TWW of this plant is directed to the trapezoidal channel on the eastern side of the treatment plant. The length of this channel is 35 km and it passes through the agricultural lands of Borkhar plain and then reaches Segzi desert. Figure 1 presents the position of the north treatment plant and the channel of TWW distribution.

Borkhar county, as part of Borkhar plain, has an area of 1,953 km$^2$, a population of 122,419, orchards and agricultural croplands under cultivation with an area of 15,372 hectares, 1,054 hectares of green space, 4,739 hectares of man-made forests, 4,509 hectares of desert forest, and two industrial towns known as Dowlatabad and Komshecheh. Data and information obtained from the Regional Water Company (list of consumers and demands for TWW of this treatment plant) and visits to the treatment plant's outlet channel demonstrated that currently, most of the agricultural lands in this area are located near the TWW outlet channel. As a result, farmers in the agriculture sector use most of the TWW of the treatment plant. Most of these farmers or their ancestors received the right to use the TWW in exchange for selling their land to the Water and Wastewater Company, and are not willing to share this right with the other sectors. But, on the other hand, Borkhar city is located in the forbidden plain (based on the drop of groundwater level in the wells of certain plains of Iran (forbidden plains), the Ministry of Energy of this country has forbidden the drilling of new wells in those regions; therefore, drawing water from those wells has to be according to regulation) and according to the circular on the use of TWW in the Iranian treatment plants (2014), agricultural development using wastewater in the forbidden plains is not allowed. These reasons and the growing demand from other sectors for TWW has created social challenges and tensions for wastewater management planning of this city. Moreover, the report of the comprehensive effluent studies in Isfahan

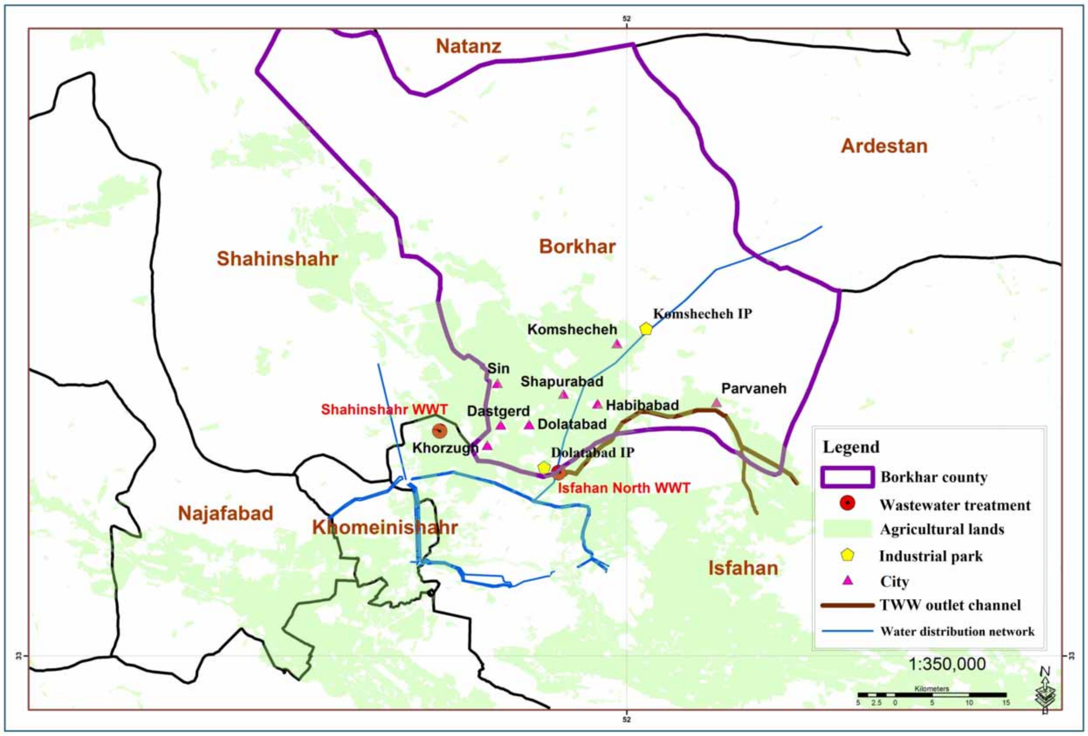



**Figure 1** | Position of Isfahan's north wastewater treatment plant and the distribution channel of TWW.

province has shown that other sectors in this area also have the potential to use effluent (Regional Water Company of Isfahan 2017). Therefore, the present study has assessed the priority of consumption in four sectors demanding TWW use: agriculture, industry (excluding food industry), urban green space and natural resources (desertification projects).

## METHODOLOGY

This study prioritizes the allocation of TWW for users in the study area by using the risk and social acceptability indexes. Because these indexes can lead to different results regarding the ranking of the sectors, while the present study uses expert-oriented structures for estimating both indexes, it also tries to find a solution to analyze and prioritize the economic sectors by the introduction of GRA as one of the MCDM approaches.

In MCDM, the decision-making process is conducted under the presence of different and partly opposed criteria. Despite the extensive use of MCDM, these models are divided themselves into multi-objective decision-making (MODM) and multi-attribute decision-making (MADM) models. MODMs are usually used to design, while MADMs are utilized to select the best alternatives. An MADM problem which forms the structural basis of the present study can be summarized in the matrix of decision-making, in which the rows represent alternatives and cells within the matrix indicate the position of the row alternative relative to the corresponding column index (Khedrigharibvand *et al.* 2019). Figure 2 shows details of the decision-making structure of this study as a conceptual framework and all models used in this structure are separately described in the following sections.

### Estimating and analyzing the risk index

In order to recognize and evaluate the hazards of using effluent of Isfahan's north wastewater treatment plant in various sectors, an expert assessment system was designed and implemented by using general risk assessment approach and considering the assessment technique of Frank and Morgan (Frank & Morgan 1979). The Frank and Morgan technique is one of the available quantitative techniques used for assessing risk to determine and evaluate the risk related to working units (Brauer 2006). The calculation of risk index in the present study involves three fundamental steps.

*Step 1 Questionnaire completion by chosen experts*:

The hazard and control measures checklists were designed in the form of scoring tables by applying the

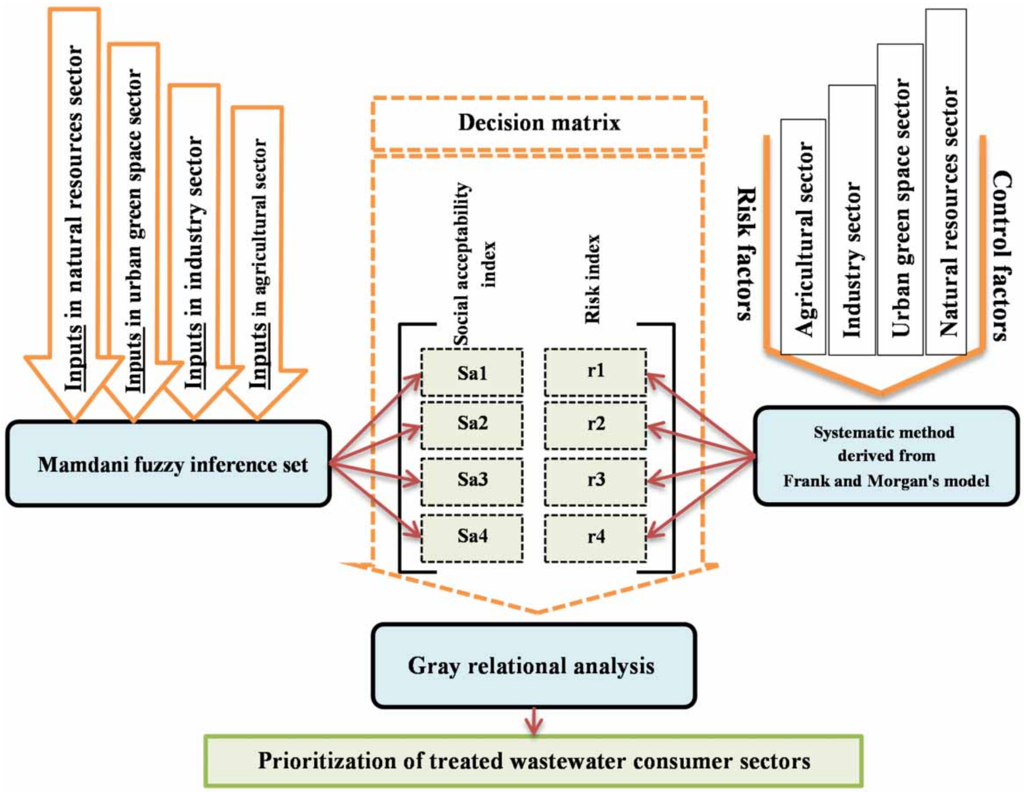



**Figure 2** | Conceptual framework of MCDM model of this study.

viewpoints of experts in the present study. This is contrary to the other studies, which have been derived by the Morgan technique and have used the Morgan predetermined checklists. The questions of hazard checklists were designed to represent the absence (score = 0) and presence of any hazards (score of 1–5 based on the five-point Likert scale) in each sector comparatively. The measures of control schemes were designed to determine the feasibility of implementing these schemes in each sector by their relevant experts. A questionnaire was attached to the checklists by using general risk assessment approach, in which the probability and severity of hazards and control measures were scored by the expert panel. Finally, the grade of each hazard group and control measure was calculated by multiplying probability by severity for any expert's opinion.

*Step 2 Determination of hazard, control, and risk scores*:

The risk score of each sector in each questionnaire was calculated by assessing hazards and control schemes. The hazard checklist consists of j sectors and k groups of hazards, where each group was divided into i subgroups.

To calculate the hazard score of each sector, at first, the score of each subgroup is determined based on the five-point Likert scale, then the score of k-th hazard group in j-th sector ($X_{kj}$) is calculated by summing the scores of subgroups as Equation (1). In this equation, $i(K)$ represents the number of k-th hazard subgroups, and $x_{i(kj)}$ is the score of i-th subgroup related to k-th hazard group in j-th sector.

$$X_{kj} = \sum_{i=1}^{i(K)} x_{i(kj)} \tag{1}$$

After determining the score of each group, by considering the grading form of each hazard group, the grade of k-th hazard group in j-th sector ($Y_{kj}$) is calculated by Equation (2):

$$Y_{kj} = SH_{kj} \times PH_{kj} \tag{2}$$

where:

($SH_{kj}$) is the severity of the impact of k-th hazard group in j-th sector,

($PH_{kj}$) is the probability of occurrence of k-th hazard group in j-th sector.

Considering the Equations (1) and (2), the hazard score of j-th sector ($H_j$) is calculated by using Equation (3):

$$H_j = \sum_{k=1}^{K} (X_{kj} \times Y_{kj}) \tag{3}$$

Control schemes cannot be grouped similar to hazards because some of them were common among hazard groups. Thus, the score of each control scheme is equal to the control grade of that sector if the probability of its implementation in the relevant sector is not equal to zero.

The control score of j-th sector ($C_j$) is calculated by Equation (4), in which Z represents the number of the control schemes existing in the control checklist.

$$C_j = \sum_{z=1}^{Z} (SC_{zj} \times PC_{zj}) \qquad (4)$$

where:

($SC_{zj}$) is the impact severity of z-th control measure in reducing the hazards of j-th sector,
($PC_{zj}$) is the probability of implementing z-th control measure in j-th sector.

The risk score of j-th sector ($r_j$) is determined by subtracting the hazard score of j-th sector from its control score as Equation (5):

$$r_j = C_j - H_j \qquad (5)$$

*Step 3 Ranking the sectors based on their risk index*:

For ranking the sectors, calculating the percentage of relative risk and risk index is essential. The percentage of relative risk score in j-th sector ($rr_j$) is determined by using Equation (6). Since Equations (1)–(6) are separately calculated for each expert, the risk index of each sector ($R_j$) is determined by averaging the viewpoints of experts through Equation (7). After comparing risk index among sectors, the sector having minimum risk index is prioritized for allocating TWW.

$$rr_j = \frac{Mr - r_j}{\sum_{j=1}^{J} (Mr - r_j)} \qquad (6)$$

$$R_j = \frac{1}{N} \sum_{n=1}^{N} rr_{j(N)} \qquad (7)$$

where:

($Mr$) is the maximum of $r_j$ or the maximum of risk scores,
($rr_{j(N)}$) is the percentage of the relative risk score of j-th sector based on the viewpoint of N-th expert.

## Estimating and analyzing social acceptability index

In this paper, fuzzy modeling is used to calculate social acceptability index and fuzzy logic toolbox in MATLAB software is used to design the fuzzy model.

Fuzzy inference sets implement human experience using membership functions and fuzzy rules and provide a general way of combining knowledge, intelligent technology, control, and decision-making. The most important fuzzy inference systems are pure fuzzy systems, Takagi-Sugeno-Kang and fuzzy system with fuzzifier and defuzzifier (Mamdani set) (Wang & Chen 2014).

In the fuzzy model designed for this research, the Mamdani Fuzzy Inference Set is used, which is a knowledge-oriented system and more capable than other systems in utilizing the expertise and opinions of experts. The Mamdani method (minimum inference engine) uses the minimum operator for fuzzy intersection and the maximum operator for fuzzy union (Mamdani & Assilian 1975). Figure 3 presents the diagram of the codified fuzzy model for calculating social acceptability index.

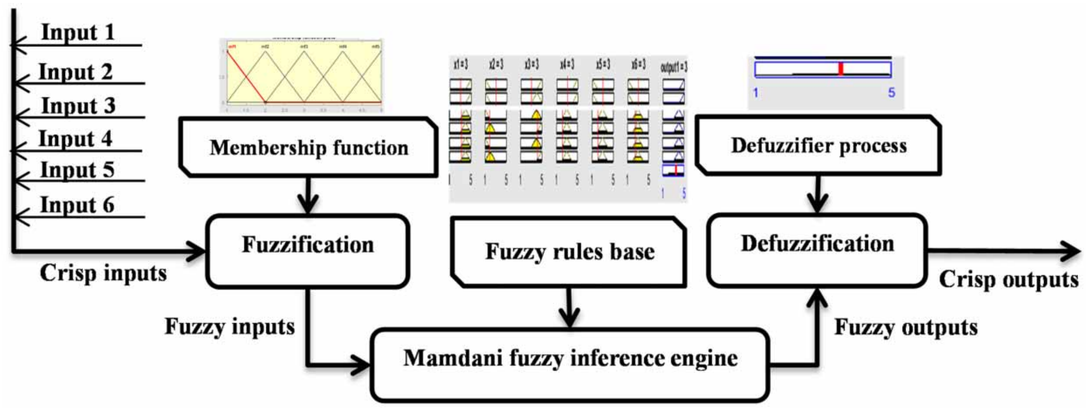



**Figure 3** | Mamdani fuzzy inference set.

Mamdani fuzzy inference set has three main components including fuzzy rule base, fuzzy input–output sets, and fuzzy inference engine. Inputs in Mamdani set are always crisp or defuzzy values. Fuzzification is defined as the trend of converting crisp variables to linguistic ones. The fuzzification of inputs is conducted based on the membership functions, which are defined for each input. Each input variable is designed in five fuzzy sets including very high (VH), high (H), moderate (M), low (L) and very low (VL). Furthermore, triangular-shaped membership function is used to determine membership grade. The output defined for this system involves five fuzzy sets similar to inputs, which allows for a more precise reporting of the output levels of the system and their values (Mostafaei *et al.* 2016; Sun *et al.* 2018).

Fuzzy rules of the present study are selected and written using the ideas and knowledge of the researchers (authors of this paper) and experts (the main experts of the panel (17 persons)), who are familiar with fuzzy logic and the utilization cases of effluent. In this approach, fuzzy rules are maximized and as a result, more precise results are obtained based on the different combinations of input. Finally, 258 rules were considered in fuzzy inference set and social acceptability index in four sectors was separately calculated.

Inference engine assesses and infers rules by using inference algorithm, and the defuzzifier unit converts the output to explicit or numeric values after aggregating the rules (Sumathi & Paneerselvam 2010).

The different types of defuzzification methods include center of gravity (COG), bisector of area, smallest of maximum, largest of maximum, mean of maximum, weighted average, and weighted sum (Wang & Chen 2014). COG is the most common and reliable method in different situations, although generally no defuzzification method can be preferred to others. COG is based on finding a point, which is placed in the geometric center of the area of combined fuzzy subsets (Sun *et al.* 2018). This method is used in this study. Finally, the sector having higher social acceptability is prioritized for using TWW by comparing the defuzzy outputs of the four sectors.

## Making decision and allocating TWW optimally

Decisions which are made in today's dynamic world involve high uncertainty and consideration (Zhang *et al.* 2005). Gray system theory, as a relatively new mathematical theory derived from gray sets, provides an efficient tool to solve problems with low and inadequate data on discrete space. This theory was developed by Deng (1982) based on the concept that information might be defective or unknown and came quickly to the attention of researchers in the field of MCDM (Yin 2013).

GRA, as a part of gray system theory, is used in the present study to allocate TWW optimally based on the two indexes of risk and social acceptability. This decision-making model is an algorithm which analyzes the uncertain relationships of members in a system with a reference member and can be used for solving MCDM problems. Five steps are considered for this algorithm to calculate relationships among alternatives with the reference alternative (Li *et al.* 2019; Zhu *et al.* 2019).

In the first step, a decision matrix is created in which the status of each alternative is specified for each criterion. The columns and rows of this matrix represent the assessment criteria and alternatives under study, respectively.

In the second step, the normalization of data is conducted by considering specific relationships affected by the nature of that distinct criterion and the data are considered between zero and one. In this regard, after assessing the intended criterion and considering its nature, one of the following three situations might occur. In these three situations, $min_i(x_{ij})$ and $max_i(x_{ij})$ represent the minimum and maximum values of each column (Wang *et al.* 2015; Zhu *et al.* 2019).

(a) The data are normalized by using Equation (8) if desirability of the criterion increases by adding to its value (the larger the better):

$$P_{ij} = \frac{X_{ij} - min_i(x_{ij})}{max_i(x_{ij}) - min_i(x_{ij})} \tag{8}$$

(b) Equation (9) is used to normalize data if desirability of the criterion reduces by increasing its value (the smaller the better):

$$P_{ij} = \frac{max_i(x_{ij}) - X_{ij}}{max_i(x_{ij}) - min_i(x_{ij})} \tag{9}$$

(c) Equation (10) is utilized if each criterion has its desirable value (target value). Desirable value is predetermined and is defined by considering the type of index under study. $X_{obj}$ indicates desirable value for j-th criterion.

$$P_{ij} = 1 - \frac{|X_{ij} - X_{obj}|}{max(max_i(x_{ij}) - X_{obj},\ X_{obj} - min_i(x_{ij}))} \tag{10}$$

The normal matrix of P is then generated based on probabilities. Each element in this matrix is placed in the range of zero and one and the closeness of the obtained value to one represents the higher desirability.

The maximum number of each column in the normal matrix represents the reference number ($P^*(\mathrm{j})$). The row which consists of the reference numbers in the columns of the matrix and is placed on top of the normal matrix is the reference row which is calculated through Equation (11) (Sun 2014):

$$P^*(\mathrm{j}) = max_i p_i(j) \tag{11}$$

In the third step, after creating the reference row, elements of a new matrix named delta are obtained by Equation (12):

$$\Delta_i^*(j) = |P^*(\mathrm{j}) - P_i(\mathrm{j})| \tag{12}$$

In the fourth step, the gray relational coefficient is calculated for each element in the delta matrix, representing the amount of relationship between that element and the corresponding criterion in the reference alternative. This coefficient is determined by Equation (13) (Kuo *et al.* 2008; Hsu *et al.* 2015):

$$\gamma_i(j) = \frac{min_i\ min_j\ \Delta_i^*(j) + \varepsilon \times max_i\ max_j\ \Delta_i^*(j)}{\Delta_i^*(j) - \varepsilon \times max_i\ max_j\ \Delta_i^*(j)} \tag{13}$$

where $min_i\ min_j\ \Delta_i^*(j)$ and $max_i\ max_j\ \Delta_i^*(j)$ indicate the minimum and maximum of $\Delta_i^*(j)$ in the j-th column of the $\Delta$ matrix respectively and $\varepsilon$ as the coefficient of differentiation represents the importance of $max_i\ max_j\ \Delta_i^*(j)$ in calculating gray coefficient. The value of $\varepsilon$ is in the range of zero and one and lower $\varepsilon$ results in higher differentiation (Wang *et al.* 2015). The value of $\varepsilon$ is assumed to be equal to 0.5 due to balanced differentiation.

In the fifth and final step, gray relational grade is calculated by Equation (14) (Wang *et al.* 2015).

$$r_i = \sum_{j=1}^{n} (w(j) \times \gamma_i(j)), \quad \sum_{j=1}^{n} w(j) = 1 \tag{14}$$

In this equation, $w(j)$ represents the weight of j-th criterion, which usually depends on the judgment of the decision maker or the structure of the proposed problem. In this study, it is assumed that the weights of the criteria are equal. Considering the gray grade, the best alternative is selected.

## Collection of information and interpretation of variables

The information required for calculating the two indexes of risk and social acceptability was collected and measured by an expert panel in 2016. The selection of eligible members for this kind of panel is one of the most important steps in expert-oriented models because the reliability of the results depends on their competence and knowledge. In this study, the panel members were not selected based on probability sampling like quantitative surveys because group decision-making methods require specialists who have in-depth perception and knowledge about the subject of the study. Since it is hard to recognize all of the panel members in the area under study, chain referral or snowball sampling, as a type of non-probability sampling, was used. In this method, the researcher starts to determine members by identifying one or a group of informed persons and subsequently finds other intended persons (Wright & Stein 2005).

The main group of experts in the present study involved 17 managers aware of the production and distribution of Isfahan north wastewater treatment plant's effluent employed in the Water and Wastewater Company, Regional Water Company, Organization of Parks and Green Space, Organization of Agriculture Jahad, Agricultural and Natural Resources Research Center, Department of Natural Resources and Watershed Management, and municipalities as well as governorates of Isfahan and Borkhar counties. Considering the chain referral method, each selected manager introduced informed experts in Isfahan and Borkhar to complete the expert panel. The chain of introducing experts ended at the final number of 69 experts (21 persons with water and wastewater specialty, 9 persons with agricultural specialty, 9 persons with industrial specialty, 9 persons with green space specialty, 9 persons with natural resources specialty, 12 persons with health and environment specialty).

After field surveys of the north treatment plant and the distribution channel of TWW, the hazard checklist with six hazard groups and the control checklist with 12 control measures were prepared by the main experts of the panel (17 persons) in order to assess the risk of TWW use (Table 1). These checklists and the scoring guideline were distributed as a risk questionnaire among the panel of 69 experts.

To specify the input variables determining the social acceptability index, eight variables were recognized by the assessment of available documents and reports about the north treatment plant and face-to-face interviews with the experts of water, wastewater, and regional water companies in Isfahan province. The 17 main experts were provided with the list of variables for final confirmation and

**Table 1** | The six items of the hazard checklist

| No. | Title of hazard group | Number of subgroups |
|---|---|---|
| 1 | Hazards to humans | 4 |
| 2 | Hazards to water resources | 2 |
| 3 | Hazards to soil resources | 1 |
| 4 | Hazards to air | 3 |
| 5 | Hazards to biodiversity | 2 |
| 6 | Hazards to property value | 3 |
| | Total | 15 |

each expert was asked to assign a score of 1–10 to each factor. After collecting the lists, the scores of members were averaged and six variables having a score over 7 were selected as variables determining the social acceptability index. Since correlation between input variables represents the same condition, high overlap or correlation between variables was one of the reasons for reducing variables according to the experts' opinion. The variables under study and their codes in MATLAB software are summarized in Table 2.

**Table 2** | Codification of inputs in the fuzzy inference system of social acceptability

| Variable (Belief in) | Concept code (Input) |
|---|---|
| the necessity of TWW use | 1 |
| negative impact on health | 2 |
| impact on the sustainability of employment | 3 |
| impact on protecting the water security of the area | 4 |
| paying attention to jurisprudential requirements of TWW use | 5 |
| complexity of the rules governing TWW use | 6 |

According to these explanations, two types of questionnaire including risk questionnaire and social acceptability questionnaire were distributed in the expert panel (69 persons) and explained to them. However, in the end, 52 social acceptability questionnaires and 69 risk questionnaires were completed by experts and are examined in this study.

## RESULTS AND DISCUSSION

Hazards affecting humans, water resources, air, biodiversity and property value were calculated by Frank and Morgan technique, which was developed in the present study to assess the risk of TWW use in the four sectors of agriculture, industry, green space, and natural resources. Table 3 shows the summarized results. Based on the results, the average score of the six items in the hazard checklist regarding the agriculture sector has obtained a higher amount compared with other sectors and a higher score was achieved in the hazards affecting humans in four sectors compared with that of other hazards. Furthermore, the hazards affecting humans in the agriculture sector were 5, 3 and 2 times more than that in the industry, natural resources, and green space sectors respectively. There are some reasons that have led to the higher estimation of score related to these hazards in the agriculture sector compared with that in other sectors. These are the presence of extensive agricultural lands adjacent to the distribution channel of TWW, use of flood irrigation in agricultural lands, high contact of workers, animals, and plant species with TWW in use, the release of unpleasant odor in the area under study, and great probability and severity of the damages affecting water and soil resources, air, and biodiversity. Table 3 also presents hazards affecting property value. In fact, experts

**Table 3** | Results of calculating the risk index in different sectors

| Description | | Sectors | | | |
|---|---|---|---|---|---|
| | | Agriculture | Industry | Green space | Natural resources |
| Average score of hazards affecting | humans | 316.35 | 57.61 | 172.22 | 99.65 |
| | water resources | 140.96 | 25.78 | 73.87 | 53.13 |
| | soil resources | 75.52 | 10.48 | 49.39 | 43.83 |
| | air | 90.35 | 36.78 | 71.00 | 51.26 |
| | biodiversity | 69.78 | 13.39 | 39.91 | 61.13 |
| | property value | 87.35 | 35.52 | 46.87 | 23.26 |
| Average score of the hazards | | 780.30 | 179.57 | 453.26 | 332.26 |
| Average of the control score | | 139.09 | 175.17 | 163.43 | 148.52 |
| Risk index | | **54.71** | **6.22** | **23.97** | **15.10** |

believe that TWW use in the agriculture sector decreases the value of the agricultural lands, which have been irrigated for a long time with TWW, in addition to damaging the equipment and devices in contact with TWW which in turn lose their value. Thus, high severity and probability of occurrence of these hazards in the agricultural sector had resulted in attaining a greater average score for the hazards affecting property value in this sector compared with other sectors. Based on these results and considering these conditions, experts in the study area believed that the hazards of using Isfahan north wastewater treatment plant's effluent in the agriculture sector were more than that in other sectors. It is not enough to calculate just the hazard scores for calculating the risk of effluent use and it is essential to consider the probability of implementing control measures in each sector and score their severity of impact. Table 3 also provides the results of calculating control scores. Based on these results, there is a higher hazard score in agriculture sector compared with that in the industry sector and a greater control score in the industry sector compared with that of the agriculture sector.

Risk indexes in the four sectors are shown in the ninth row of Table 3 derived from using Equations (1)–(7). The risk index of the agriculture, green space, natural resources, and industry sectors were 54.71, 23.97, 15.1, and 6.22% respectively. Generally, the agriculture sector obtained the maximum risk index and priority for risk reduction, and the priority for allocating effluent was considered as the industry, natural resources, and green space sectors respectively.

Social acceptability questionnaires were prepared and filled along with the completion of hazard and control checklists. To this end, the six variables explained in Table 2 were scored by experts and considered as the input of Mamdani fuzzy inference set. Table 4 represents input values and output results, in which the values of crisp input and crisp output columns indicate each input value in each sector and the output of fuzzy system or social acceptability index of each sector respectively. The value of each index is defined as the value obtained by COG defuzzifier, after defuzzificating outputs. Thus, these values represent the COG of output fuzzy sets. Considering the obtained indexes, the social acceptability of TWW use is moderate in all sectors, while there is a higher social acceptability for using north wastewater effluent in the natural resources sector. The priorities for TWW use are the natural resources, industry, green space, and agriculture sectors respectively.

In order to determine the impact severity of the inputs on the output and to compare them, one input was varied and others were fixed in their optimum conditions. To this end, a loop with 0.1 steps was written by considering the six inputs in the specified system of social acceptability. The output of this program is a matrix of seven columns and 41 rows, in which the first column includes the values of zero to one with 0.1 steps, while the rest of the six columns include the outputs of the system by assuming that five variables were constant and one variable could change. Figure 4 shows the relationship between the variable values and output values using dispersion diagram to analyze the data simulation precisely and rapidly.

Some of the main results which were derived from comparing the 6 dispersion diagrams and could be used as a base for recognizing the variable which possesses the maximum effect on social acceptability are:

1. System output can increase to more than 4.5 by maximizing the membership grade of "belief in the necessity of TWW use", "belief in impact on the sustainability of employment", and "belief in impact on protecting the water security of the area".
2. System output can increase to more than 4.5 by minimizing the membership grade of "belief in the negative impact on health", "belief in paying attention to the jurisprudential requirements of TWW use", and "belief in the complexity of the rules governing TWW use".
3. The effects of "belief in the necessity of TWW use", "belief in impact on the sustainability of employment", and "belief in impact on protecting the water security of the area" can be considered as increasing, while the effects of 'belief in paying attention to the jurisprudential requirements of TWW use" and "belief in the complexity of the rules governing TWW use" are regarded as decreasing. This change in the variable of "belief in impact on the sustainability of employment" starts with the membership grade of 2.

**Table 4** | Inputs and output of Mamdani fuzzy inference set

| Sector | Crisp inputs 1 | 2 | 3 | 4 | 5 | 6 | Crisp output |
|---|---|---|---|---|---|---|---|
| Agriculture | 3.38 | 4.23 | 3.69 | 3.69 | 4.15 | 3.69 | 2.64 |
| Industry | 3.23 | 1.88 | 4.15 | 2.15 | 2.19 | 2.50 | 3.50 |
| Green space | 3.23 | 2.88 | 2.96 | 3.31 | 3.08 | 2.62 | 3.29 |
| Natural resources | 3.50 | 2.04 | 2.69 | 3.73 | 2.04 | 2.50 | 3.64 |

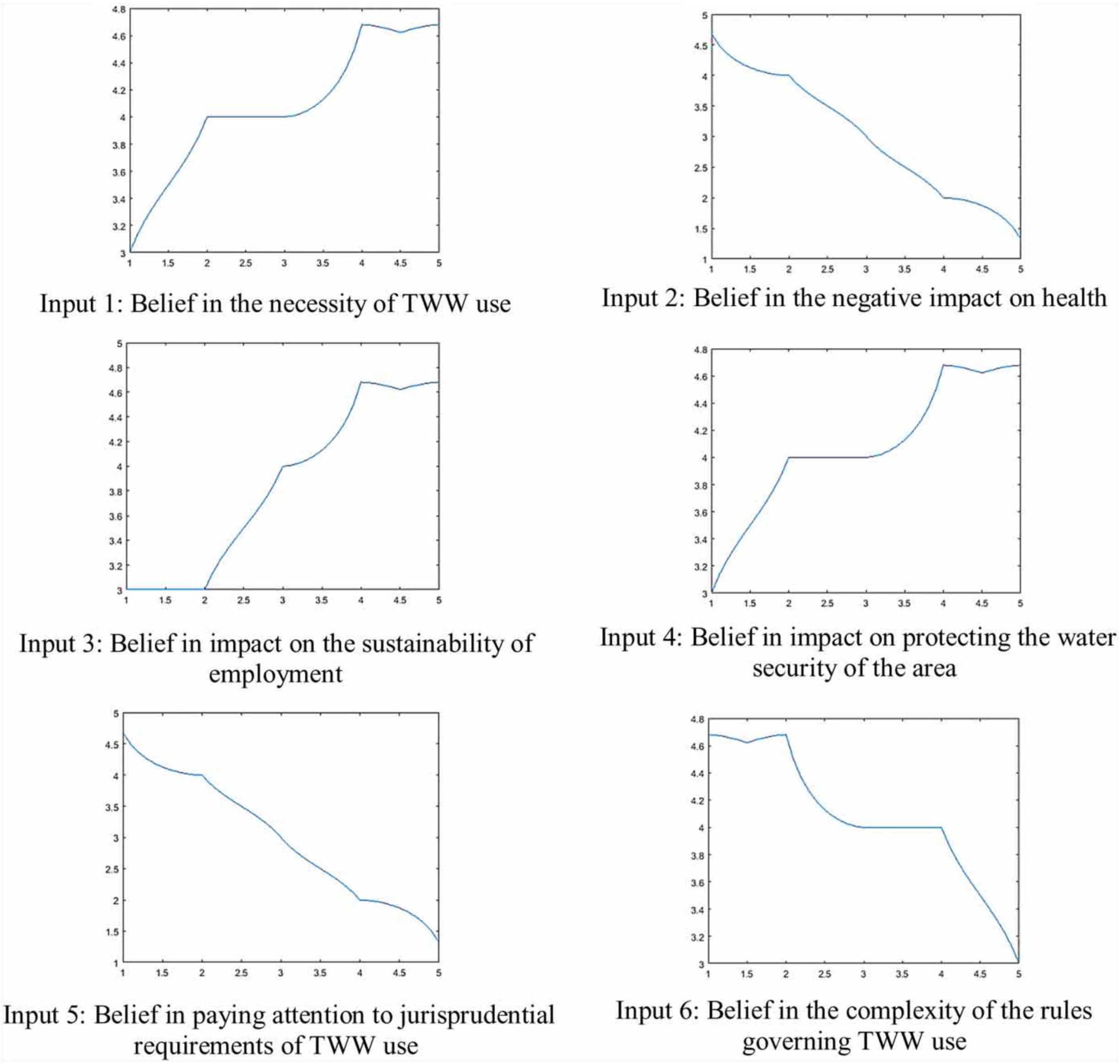



**Figure 4** | Assessment of changes in the system's output by varying one input (the x-axis and y-axis represent the membership grade of input and output (social acceptability), respectively).

4. The membership grade of social acceptability changes from 3 to more than 4.5 with the changing of the variables of "belief in the necessity of TWW use" and "belief in impact on protecting the water security of the area".
5. The membership grade of social acceptability changes from more than 4.5 to less than 1.5 with the varying of the variables of "belief in the negative impact on health" and "belief in paying attention to the jurisprudential requirements of TWW use".
6. The membership grade of social acceptability changes from more than 4.5 to 3 with the changing of the variable of "belief in paying attention to the jurisprudential requirements of TWW use".

Based on the results derived from diagram analysis, the maximum impact on social acceptability is obtained from the variables of "belief in negative impact on health" and "belief in paying attention to the jurisprudential requirements of TWW use", while "belief in impact on the sustainability of employment" has the least impact on social acceptability.

The results of this study correspond with the findings of other studies which have assessed the importance of various types of effluent application. In these studies, the least important TWW uses are the ones that are directly or indirectly harmful to human health and the biggest concern of the general public is regarding the health hazards of TWW use when people come in contact with effluent (Buyukkamaci & Alkan 2013; Elsokkary & Abukila 2014; Baawain *et al.* 2020). Thus, people's belief in the negative impact of TWW on the health of organisms is the most important deterrent for accepting effluent use in sectors such as agriculture.

As mentioned before, the GRA method is used for making the final decision about the priority for TWW use in different sectors after estimating the two indexes of risk and social acceptability. Based on these two indexes, the decision matrix is defined as in Table 5, in which the columns represent the two indexes of social acceptability (sa) and risk (r), and the rows refer to the economic sectors.

Equation (10) (case c) is used to normalize the decision matrix since the intended criteria have the desirable value (0 for risk and 5 for social acceptability). The normalized matrix was calculated as the P matrix and based on the results of this matrix the reference row ($P^* = [0.89, 0.42]$) was determined. Then, the delta and gray relational coefficient matrixes were calculated using the reference row and the proposed steps in the methodology. The relevant results are shown in the $\Delta$ and $\gamma$ matrixes.

$$P = \begin{bmatrix} 0 & 0 \\ 0.89 & 0.36 \\ 0.56 & 0.28 \\ 0.72 & 0.42 \end{bmatrix} \quad \Delta = \begin{bmatrix} 0.89 & 0.42 \\ 0 & 0.06 \\ 0.32 & 0.15 \\ 0.16 & 0 \end{bmatrix}$$

$$\gamma = \begin{bmatrix} 0.33 & 0.51 \\ 1 & 0.88 \\ 0.58 & 0.75 \\ 0.73 & 1 \end{bmatrix}$$

Due to the identical importance of both criteria with respect to the viewpoint of experts, their weight was assumed equal. Gray relational grade (r) of each alternative was determined using Equation (14). Table 6 represents the summarized results based on the rank of each sector.

Based on the results of the gray rank, the priority for allocating the north treatment plant's effluent are the industry, natural resources, green space, and agriculture sectors respectively. Although there are no similar studies that are completely consistent with the topic of the present study, the comparison of the results of the present study with previous studies that have considered the possible reuse of TWW indicates that people accept the use of TWW for industrial purposes and irrigation of inedible products (kantanoleon et al. 2007; Baawain *et al.* 2020). However, in those previous studies the quantification and prioritization of the potentials of effluent use have not been considered. The present study has assessed the priority for effluent use on selected cases by quantifying two indexes of risk and social acceptability and the utilization of decision-making models, which are the main innovations of this study.

## CONCLUSION

According to gray theory and social acceptability and risk indexes used in this study the priorities for TWW use are the industry, natural resources, green space, and agriculture sectors respectively. Furthermore, the industry and natural resources sectors achieved the first and second priority for TWW use compared with other sectors by using GRA method. However, the priority is assigned to natural resources and industry sectors based on social acceptability and risk indexes respectively. The results of the interviews with experts demonstrated that currently the industries in the area of study have no demand for TWW use due to economic recession. Thus, the priority for allocating TWW is granted to the natural resources sector if the conditions remain like this. Based on the viewpoint of experts, existing and expanding deserts can lead to many environmental, economic and health problems and therefore allocating TWW use to the natural resources sector with the purpose

**Table 5** | Decision matrix

| | Indexes | |
|---|---|---|
| **Alternatives** | **Sa** | **R** |
| A1: Agriculture | 2.64 | 54.71 |
| A2: Industry | 3.50 | 6.22 |
| A3: Green space | 3.29 | 23.97 |
| A4: Natural resources | 3.64 | 15.10 |

**Table 6** | Results of prioritizing the economic sectors based on the results of the gray rank

| Sector | Priority | Gray rank |
|---|---|---|
| Industry | 1 | 0.94 |
| Natural resources | 2 | 0.87 |
| Green space | 3 | 0.66 |
| Agriculture | 4 | 0.42 |

of cultivating different plant species can reduce some of the aforementioned problems by preventing the dispersion of dust.

The results of simulating input data in Mamdani fuzzy inference set indicates that the maximum effect of accepting TWW use is observed in the variable of "belief in negative impact on health". Moreover, the results of hazard scores in the Morgan model demonstrate that the maximum score of the hazards affecting humans was obtained in the agriculture sector among all the sectors and scores. "Belief in negative impact on health" in the agriculture sector is one of the main reasons for placing this sector in the last priority for TWW use with respect to both indexes. Experts believe that the agriculture sector should be placed in the last priority position due to the high hazards and fewer controlling measures, even though TWW has been mostly used for the cultivation of non-productive plants in this sector in the recent years. Thus, it is suggested that the Water and Wastewater Company of Isfahan highlights this issue to allocate TWW optimally and efficiently. Furthermore, this company needs to grant permission for TWW use to water-consuming industries and the development of man-made forests, which can result in increasing employment, reducing harmful effects of dust, and decreasing water use.

Formulating the assessment steps of the Frank and Morgan technique and matching it with the objectives of this study has been one of the innovations of it. This generalized method can be used in other studies as well so that other researchers can assess the prioritization of TWW use in the areas related to their studies. The uses of the expert panel instead of the general poll, as well as the use of the fuzzy inference set, are other innovations of this study compared with similar ones. It is recommended that the factors affecting social acceptability are considered through this method and are utilized for other treatment plants of Iran in order to prioritize the allocation of TWW assessed in each area. Combining these opposed indexes and determining the priorities by using the GRA model are the main innovations of the present study. Conducting similar studies is suggested in all treatment plants, and other indexes along with these two indexes can be used in decision-making models to obtain general results and facilitate decision-making for water and wastewater managers and policymakers.

## DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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