Protocol Article

Protocol for the estimation of drinking water quality index (DWQI) in water resources: Artificial neural network (ANFIS) and Arc-Gis

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\textbf{A B S T R A C T}

Drinking water sources may be polluted by various pollutants depending on geological conditions and agricultural, industrial, and other human activities. Ensuring the safety of drinking water is, therefore, of great importance. The purpose of this study was to assess the quality of drinking groundwater in Bardaskan villages and to determine the water quality index.

Water samples were taken from 30 villages and eighteen parameters including calcium hardness (CaH), total hardness (TH), turbidity, pH, temperature, total dissolved solids (TDS), electrical conductivity (EC), alkalinity (ALK), magnesium (Mg\textsuperscript{2+}), calcium (Ca\textsuperscript{2+}), potassium (K\textsuperscript{+}), sodium (Na\textsuperscript{+}), sulphate (SO\textsubscript{4}\textsuperscript{2-}), bicarbonate (HCO\textsubscript{3}\textsuperscript{-}), fluoride (F\textsuperscript{-}), nitrate (NO\textsubscript{3}\textsuperscript{-}), nitrite (NO\textsubscript{2}\textsuperscript{-}) and chloride (Cl\textsuperscript{-}) were analyzed for the purpose for this study. The water quality index of groundwater has been estimated by using the ANFIS. The spatial locations are shown using GPS. The results of this study showed that water hardness, electrical conductivity, sodium and sulfate in 66, 13, 45 and 12.5% of the studied villages were higher than the Iranian drinking water standards, respectively. Based on the Drinking Water Quality Index (DWQI), water quality in 3.3, 60, 23.3 and 13.3% of villages was excellent, good, poor and very poor, respectively.

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Groundwater is one of the sources of drinking water in arid and semi-arid regions such as Bardaskan villages, which monitor the quality of these resources in planning for improving the quality of water resources.

The DWQI can clearly provide information associated with the status of water quality resources in Bardaskan villages.

The results of this study clearly indicated that with appropriate selection of input variables, ANFIS as a soft computing approach can estimate water quality indices properly and reliably.

Some parameters were in the undesirable level is some villages. Therefore, the government should try to improve the chemical and physical quality of drinking water in these areas with the necessary strategies.

Specifications Table

| Subject area: | Environmental Sciences |
|---------------|------------------------|
| More specific subject area: | Drinking Water Quality Index (DWQI) |
| Protocol name: | Estimation a water quality index in Bardaskan city |
| Reagents/tools: | pH meter (model wtw), turbidity meter (model Hach 50161/co 150 model P2100Hach, USA), spectrophotometer (model DR 5000). Arc-GIS and MATLAB |
| Experimental design: | The mentioned parameters above, were analyzed according to Standard Methods for the Examination of Water and Wastewater. |
| Trial registration: | MATLAB:271828 and GIS: 10.4.1 |
| Ethics: | No applicable |

Description of protocol

Clean water is necessary for human communities and generally it is a necessary input to human production and an important tool of economic development [1]. It has a considerable role in social prosperity and the health of human [2,3]. Water quality is dependent on water composition and can be affected by natural process and human activities [4]. Aquifers are important freshwater sources that provide human with water for many purposes such as drinking, agricultural, industrial and recreation [5]. Water resources in many Iranian urban and rural areas face serious threats deriving from groundwater pollution, increasing industrial and agricultural activities coupled with environmental pollution and improper management of all types of wastes [6–9]. After contamination, the restoration of its quality groundwater quality is difficult it usually takes a long time to regain its natural state [10,11]. Consistent and regular monitoring of groundwater quality in a region identifies areas with potential environmental health problems. Recently, water quality indices have been considerably used by many researchers in many nations [12–18]. Drinking Water Quality Index (DWQI) gives a numerical value that shows overall quality of water, by considering the different physico-chemical parameters of water at a certain location and time [19–21]. The distribution map of DWQI in the studied villages are shown using GIS software.

Materials and methods

Study area description

The city of Bardaskan is located in Razavi Khorasan Province, in eastern Iran. The city covers an area of 7664 km², located between 35° 15'N and 57° 58'E. Neighboring cities of the Bardaskan are Sabzevar
Bardaskan’s temperature in the hottest summer day is nearly 45 °C and in the coldest winter night is −5 °C and the average annual precipitation is 150 mm. Location of the study area in Bardaskan city in Khorasan Razavi and in Iran is shown in Fig. 1.

Fig. 1. Location of the study area in Bardaskan city, Khorasan Razavi, Iran.

Fig. 2. Checking and training errors DWQI for optimization of epochs.
**Sample collection and analysis**

All the chemicals used in this study were of analytical grade and were purchased from the Merck. A total of thirty (30) water samples were taken for main drinking water resources of 30 villages of Bardaskan during 2016–2017. Villages were coded as 1–30. All samples were collected in polyethylene bottles and then transferred to water and wastewater laboratories at temperatures below 4 °C. Eighteen (18) parameters including calcium hardness (CaH), total hardness (TH), turbidity, pH, temperature, total dissolved solids (TDS), electrical conductivity (EC), alkalinity (ALK), magnesium (Mg²⁺), calcium (Ca²⁺), potassium (K⁺), sodium (Na⁺), sulphate (SO₄²⁻), bicarbonate (HCO₃⁻), fluoride (F⁻), nitrite (NO₃⁻), nitrate (NO₂⁻) and chloride (Cl⁻) were analyzed for the purpose of this study. All water samples were analyzed using standard method for the examination of water and wastewater. Titrimetric method was used for hardness, magnesium, calcium and chloride determination [22–25]. pH was analyzed with pH meter (model wtw, Esimetwrb), EC was determined with Esimetrwb device, turbidity with turbidity meter (model Hach 50161/co 150 model P2100Hach, USA). Fluoride, nitrate and sulfate were also determined by the Hach DR5000 spectrophotometer in the Bardaskan Rural Water and Wastewater Laboratory [25,26]. Finally, the results of water quality in Bardaskan villages were

**Table 1**

| Village code | CaH (mg/L as CaCO₃) | TH (mg/L as CaCO₃) | Turbidity (NTU) | pH | T (°C) | TDS (mg/L) | EC (μmhos/cm) | ALK (mg/L as CaCO₃) |
|--------------|---------------------|-------------------|-----------------|----|--------|------------|---------------|---------------------|
| 1            | 28                  | 68                | 3               | 8.38 | 22.3  | 698        | 1125        | 222                |
| 2            | 32                  | 80                | 1.09            | 8.27 | 21.2  | 556        | 897          | 180                |
| 3            | 36                  | 92                | 0.21            | 8.24 | 22.6  | 642        | 1036         | 169                |
| 4            | 36                  | 80                | 0.58            | 8.23 | 22.7  | 575        | 928          | 169                |
| 5            | 40                  | 84                | 4.58            | 8.32 | 22.5  | 613        | 989          | 147                |
| 6            | 28                  | 48                | 0.63            | 8.39 | 22.4  | 478        | 771          | 160                |
| 7            | 42                  | 92                | 0.33            | 8.29 | 20.8  | 815        | 1314         | 188                |
| 8            | 148                 | 440               | 0.23            | 7.96 | 20.2  | 811        | 1308         | 357                |
| 9            | 48                  | 92                | 0.26            | 8.33 | 20.8  | 843        | 1359         | 192                |
| 10           | 170                 | 620               | 6.3             | 8.02 | 20.0  | 1414       | 2280         | 211                |
| 11           | 110                 | 232               | 0.42            | 8.13 | 20.2  | 2864       | 4620         | 162                |
| 12           | 64                  | 148               | 0.34            | 8.26 | 20.9  | 1063       | 1714         | 102                |
| 13           | 32                  | 64                | 0.24            | 8.33 | 21.4  | 753        | 1214         | 214                |
| 14           | 64                  | 104               | 0.28            | 8.13 | 21.3  | 1045       | 1686         | 274                |
| 15           | 88                  | 116               | 0.23            | 8.04 | 26.2  | 307        | 495          | 160                |
| 16           | 184                 | 300               | 0.53            | 7.65 | 25.9  | 725        | 1170         | 293                |
| 17           | 152                 | 280               | 0.28            | 7.8  | 25.8  | 586        | 945          | 278                |
| 18           | 124                 | 156               | 0.3             | 7.89 | 25.8  | 358        | 577          | 196                |
| 19           | 136                 | 200               | 0.22            | 7.93 | 25.8  | 455        | 734          | 218                |
| 20           | 120                 | 204               | 0.26            | 8.03 | 25.8  | 650        | 1049         | 271                |
| 21           | 170                 | 270               | 0.46            | 7.88 | 25.5  | 678        | 1094         | 432                |
| 22           | 112                 | 176               | 0.25            | 8.15 | 25.6  | 878        | 785          | 229                |
| 23           | 260                 | 440               | 0.56            | 7.81 | 22.7  | 1662       | 2680         | 188                |
| 24           | 60                  | 112               | 0.47            | 8.2  | 23.1  | 1037       | 1672         | 331                |
| 25           | 36                  | 84                | 0.48            | 8.31 | 23.1  | 596        | 962          | 142                |
| 26           | 40                  | 96                | 0.47            | 8.32 | 23    | 627        | 1012         | 124                |
| 27           | 32                  | 56                | 0.33            | 8.14 | 22.7  | 443        | 715          | 139                |
| 28           | 24                  | 96                | 0.6             | 8.28 | 22.6  | 520        | 839          | 192                |
| 29           | 32                  | 124               | 0.18            | 8.47 | 21.5  | 963        | 1554         | 237                |
| 30           | 264                 | 444               | 0.27            | 7.82 | 12.8  | 1810       | 2920         | 177                |
| Mean         | 90.40               | 179.93            | 0.81            | 8.13 | 22.57 | 835.80     | 1348.13      | 211.80             |
| Max          | 264.00              | 620.00            | 6.30            | 8.47 | 26.20 | 2864.00    | 4620.00      | 432.00             |
| Min          | 24.00               | 48.00             | 0.18            | 7.65 | 12.80 | 307.00     | 495.00       | 102.00             |
| SD           | 69.14               | 142.45            | 1.38            | 0.21 | 2.71  | 521.40     | 840.99       | 72.69              |
### Table 2
Comparison of physicochemical quality of water resources of villages in Bardaskan city with the standard of drinking water of Iran during the years 2016–2017 [3,4,8,20].

| Parameter          | 1053IR Standard | Percentage of villages |
|--------------------|-----------------|------------------------|
|                    | Desirable | Limit | Desirable | Limit | More than standard |
| pH                 | 6.5–8.5   | 6.5–9  | 100       | –      | –                   |
| TDS (mg/L)         | 500       | 1500   | 70        | 20     | 10                  |
| Cl− (mg/L)         | 250       | 400    | –         | 88     | 12                  |
| SO4²− (mg/L)       | 250       | 400    | 10        | 77.5   | 12.5                |
| NO3 (mg/L)         | –         | 50     | –         | 94     | 6                   |
| NO2 (mg/L)         | –         | 3      | 100       | –      | –                   |
| Mg²⁺ (mg/L)        | 300       | 400    | 100       | –      | –                   |
| Na⁺ (mg/L)         | 200       | 200    | –         | 55     | 45                  |
| F− (mg/L)          | 0.5       | 1.5    | 65        | 35     | –                   |
| TH (mg/L as CaCO₃) | 200       | 500    | 30.5      | 35     | 66                  |
| Turbidity (NTU)    | <1        | 5      | 96.6      | –      | 3.4                 |
| EC (µmhos/cm)      | 1500      | 2000   | 13        | 74     | 13                  |
compared with Iran’s drinking water standard 1053 [27,28]. Then, in order to determine the water quality in Bardaskan villages, the DWQI was determined according to the following equations (Fig. 2). Firstly, the following equation was used to compute the relative weight [21]:

\[ Wi = \frac{\sum w_i}{\sum w_i} \]

Which is in this equation, \( w_i \) is the relative weight, \( W_i \) is the weight of each parameter and \( n \) is the number of parameters. Secondly, the quality rating scale for each parameter is calculated by dividing its concentration in each water sample by its respective standards World Health Organization and multiplied the results by 100.

\[ q_i = \left( \frac{C_i}{S_i} \right) \times 100 \]

Where, \( q_i \) is the quality rating, \( C_i \) is the concentration of each chemical parameter in each sample in mg/L and \( S_i \) is the World Health Organization (WHO) guideline for each parameter in mg/L according to the WHO. For computing the final stage of DWQI, the SI is first determined for each parameter. The sum of SI values gives the water quality index for each sample.

\[ SI = W_i \times q_i \]

\[ DWQI = \sum S_i \]

\( S_i \) is the sub-index of \( i \)th parameter, and \( q_i \) is the rating based on concentration of \( i \)th parameter and \( n \) is the number of parameters [20].

| DWQI value | Class | Explanation                  |
|------------|-------|------------------------------|
| <50        | Excellent | Good for human health     |
| 50–100     | Good          | Fit for human consumption  |
| 100–200    | Poor            | Water not in good condition |
| 200–300    | Very poor      | Need attention before use  |
| >300       | Inappropriate  | Need too much attention     |

Table 5
Relative weight of chemical of physico-chemical parameters [1,9,17,21].

| Number | Factor | Factor Weight | WHO Standard |
|--------|--------|---------------|--------------|
| 1      | K⁺     | 2             | 12           |
| 2      | Na⁺    | 3             | 200          |
| 3      | Mg²⁺   | 2             | 50           |
| 4      | Ca²⁺   | 3             | 75           |
| 5      | HCO₃⁻  | 2             | 500          |
| 6      | NO₃⁻   | 5             | 45           |
| 7      | NO₂⁻   | 5             | 3            |
| 8      | SO₄²⁻  | 4             | 250          |
| 9      | CL⁻    | 3             | 250          |
| 10     | F⁻     | 4             | 1.5          |
| 11     | TH     | 3             | 100          |
| 12     | EC     | 3             | 1500         |
| 13     | TDS    | 5             | 500          |
| 14     | pH     | 3             | 6.5–8.5      |
Modeling by neural-fuzzy systems

Adaptive network-based fuzzy inference (ANFIS), based on the first-order Sugeno fuzzy model, was used in this study [29]. This method combines multilayer feed forward back-propagation network and fuzzy inference system and takes the advantages of artificial neural networks and fuzzy logic [30,31]. Over the recent years environmental researchers have utilized this method for several tasks such as prediction, modeling, system control and decision making [32,33]. And for the final analysis of the ANFIS, MATLAB V.20178b software was used. ANFIS as a soft computing approach can estimate water quality indices properly and reliably [34,35].

Results

Results of studied parameters including hardness, pH, turbidity, temperature, total dissolved solids and electrical conductivity in water samples of Bardaskan villages are shown in Table 1. Cations and anions measured in these areas are also shown in Table 2. The comparison of quality of water resources in Bardaskan villages with Iran’s drinking water standard 1053 are listed in Table 3. The water quality index was used to compare the quality of drinking water resources in Bardaskan villages (Table 5). The classification of water quality is given in Table 4. Also, the results of drinking water quality in

| Village number | DWQI | Water quality rating | Village number | DWQI | Water quality rating |
|----------------|------|----------------------|----------------|------|----------------------|
| 1              | 87.10| Good                 | 16             | 104.39| Poor                |
| 2              | 63.93| Good                 | 17             | 90.08 | Good                |
| 3              | 73.12| Good                 | 18             | 57.13 | Good                |
| 4              | 66.29| Good                 | 19             | 69.44 | Good                |
| 5              | 70.45| Good                 | 20             | 86.18 | Good                |
| 6              | 53.82| Good                 | 21             | 93.30 | Good                |
| 7              | 86.09| Good                 | 22             | 69.83 | Good                |
| 8              | 128.21| Poor                | 23             | 206.96| Very poor          |
| 9              | 87.99| Good                 | 24             | 106.67| Poor                |
| 10             | 203.38| Very poor        | 25             | 70.08 | Good                |
| 11             | 278.04| Very poor        | 26             | 162.14| Poor                |
| 12             | 115.51| Poor               | 27             | 54.13 | Good                |
| 13             | 76.76| Good                 | 28             | 64.32 | Good                |
| 14             | 105.88| Poor               | 29             | 132.80| Poor                |
| 15             | 48.31| Excellent            | 30             | 217.18| Very poor          |

Table 7
Predicting performance in different steps of ANFIS.

| Index          | RMSE\(^a\) | R\(^2\) | MAE\(^b\) | MSE\(^c\) |
|----------------|------------|--------|-----------|-----------|
| DWQI Train     | 2.34       | 0.0875 | 1.23      | 4.59      |
| Check          | 2.33       | 0.1164 | 1.24      | 4.81      |
| DWQI-Cold Train| 2.87       | 0.1839 | 1.22      | 3.61      |
| Check          | 2.89       | 0.2808 | 0.923     | 1.09      |
| DWQI-warm Train| 3.69       | 0.1159 | 1.14      | 1.09      |
| Check          | 3.71       | 0.2028 | 1.09      | 4.03      |

\(^a\) Root mean squares error.
\(^b\) Mean absolute error.
\(^c\) Mean squared error.
Bardaskan villages based on the water quality index are shown in Table 6. Table 7 show predicting performance in different steps of ANFIS. Spatial Distribution Map of Drinking Water Quality Index is shown in Fig. 3.

Conclusions

It is important to have exact information about main drinking water parameters in order to find the source of pollution. DWQI is a good platform for proper assessment, management and protection of water resources in an area. The results showed that the values of $\text{SO}_4^{2-}$, $\text{NO}_3^-$, TH, and $\text{Na}^+$ were above the WHO and local standards in the study areas. Based on the Drinking Water Quality Index (DWQI), water quality in 3.3, 60, 23.3 and 13.3% of villages was excellent, good, poor and very poor. Therefore, regular monitoring is essential in order to ensure safe drinking water to consumers in the studied areas at the optimum level according to the WHO and national limits, especially in villages with poor and very poor water quality status. As groundwater is the main source of water by local people in Bardaskan villages, applying more audits by governmental offices on water withdrawal and its quality issues is suggested.

Conflict of interest

The authors declare have no any conflict of interests.

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