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An Innovative Index for Evaluating the Temporal-Physicochemical Classification Pattern (Case Study: Garmabdasht, North of Iran)

By Milad Kurdi, Taymour Eslamkish & Faramarz Doulati Ardejani
Amirkabir University

Abstract- This study has been focused on investigating a new index for the assessment of major ion enrichment. Also, this study has examined the temporal-physicochemical classification Model of parameters and the temporal- IEI (Ion Enrichment Index) Model from 1986-2010. The results have been presented in this study based on physicochemical water quality parameters determined in the Garmabdasht River in Golestan province. For the evaluation and classification of the Model, WHO recommendation has been used. Temporal physicochemical Model results have been examined, and most of the samples were less than authorized in the Model of pH, Cl, K, Mg, Na, and SO4 but in the Ca and HCO3 Model, approximately more than 70 percent of the samples were suitable. In addition, the TDS Model shows that in most cases, high TDS from tap water was dominated.

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AN INNOVATIVE INDEX FOR EVALUATING THE TEMPORAL PHYSICOCHEMICAL CLASSIFICATION PATTERN CASE STUDY GARMABDASHT NORTH OF IRAN

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Keywords: IEI (Ion Enrichment Index); temporal-physicochemical classification Model; Garmabdasht; IEI_{total}; vulnerable samples.

I. Introduction

Since the 1930s, the quality of water has been one of the most important subjects of environmental sciences. Since the 1980s, global water quality changes have been added to water quality sciences (Xing-hui et al. 2001). Generally, the quality of water in surface water is a function of anthropogenic impact and natural processes (Olade 1987).

To examine the water quality situation, it is important to have detailed information about the physicochemical conditions. There are many hydro chemical assessment methods. Many methods have been presented to examine the environmental quality condition, such as contamination indices and PCA (Cheng et al. 2007). One of the most important factors in making a right decision is selecting the proper method to examine quality (Qingjie et al. 2008). Many water quality models have been made by using physicochemical parameters and trend and time series analysis (Prasad et al. 2014).

Environmental quality indices are significantly implemented for processing and analyzing environmental information (Ramos et al. 2004). There are many studies on pollution indices especially by trace elements in geochemistry investigation such as contamination factor (C^i_f) and ecological risk factor (Er^i) suggested by Hakanson (1980), element enrichment factor (*EF*) suggested by Duce et al. (1975), index of geo-accumulation (I_{geo}) originally suggested by Banat et al., (2005), sum of pollution index (PI_{sum}) by Kwon and Lee (1998), degree of contamination (C_d) for background enrichment index by Caeiro et al. (2005), pollution load index (PLI) for ecological risk index by Wilson and Jeffrey (1987), marine sediment pollution index (MSPI) suggested by Shin and Lam (2001), index of metal pollution in marine sediments for the contamination index suggested by Satsmadjis and Voutsinou Taliadouri (1985), index for chemistry of the sediment quality *(I)* suggested by Chapman (1990), metal pollution index (MPI) as a contamination index suggested by Usero et al. (1996), Index for chemistry of sediment quality suggested by DelValls et al. (1998), sediment quality guideline quotient (SQG-Q) as an ecological index suggested by Long and MacDonald (1998), standard ion index (SII) suggested by Şen (2011), and metal enrichment index (SEF) suggested by Riba et al. (2002).

All of these indices have been proposed based on special condition or parameters regarding application of the indices to determine water quality and their classification. However, in these indices, there is no emphasis on physicochemical parameters, especially for EC, pH, and TDS. Although such indices have provided useful information, visual data presentation can be useful especially by considering

Author α: Ph.D. candidate, Amirkabir University, Department of Mining & Metallurgical Engineering. e-mail: milad_kurdi@aut.ac.ir.

Author σ: Assistant professor, Amirkabir University, Department of Mining & Metallurgical Engineering, 424 Hafez Ave, Tehran, Iran. e-mail: T.eslamkish@aut.ac.ir

Author ρ: Professor of Environmental Hydrogeology, University of Tehran. e-mail: Fdoulati@aut.ac.ir

physicochemical parameters. According to this motivation, a visual presentation of an index is suggested in this study as a general evaluation mechanism with special emphasis on the temporal - spatial variations of physicochemical parameters

These indices evaluate the degree of chemical status which may have a negative effect on water quality. These quality indices propose changes in various indicator factors in a single merge index that attempts to describe the water quality (Mourhir et al. 2014). The indices also grade and prioritize the areas or the ions for further research (Iwuoha et al. 2012).

Water paucity is one of the major problems in the reduction of crop production in the arid and semi-arid regions of Iran. Golestan province is the third largest cereal producer in Iran (Kurdi et al. 2014). The results presented in this study are based on physicochemical water quality parameters determined in Garmabdasht River in Golestan province, during a period of 25 years (1986-2010). This paper has focused on investigating a temporal-physicochemical classification Model based on physiochemical parameters in Golestan province. In order to achieve this purpose, each parameter was classified based on the standards and the map of the parameters based on sampling time (month versus year) has been drawn. In addition, this paper has suggested an index based on ions which can help the water quality classification. The new suggested method has mentioned *Ion Enrichment Index (IEI)*. In order to obtain such an overview indicating the ion status in Golestan province at Garmabdasht River, a classification model based on IEI has been examined. The temporal-physicochemical classification Model suggested in the present study can provide beneficial information about the past, present and future status of ion changes in the study area understood by non-scientists.

II. Materials and Methods

This paper focuses on Golestan province, the southern part of the Caspian Sea, in the Qareh Sou basin (Fig 1). The Garmabdasht is located on the northern slopes of the Alborz Mountains and the Alborz Mountains are the most important sources of water for Garmabdasht River and Qareh Sou basin. The bed of this basin is different with a source and estuary which follows from the geological status of this region and with respect to morphology the river, the region is divided into mountain and plain (Kurdi et al. 2014). As far as geological issues are concerned, in the source of river Precambrian sediments consist mainly of dark green metamorphic schist (mica schist, chlorite schist, quartzite, marble, and slate) with bright green Gorgan green schist and Mesozoic sediments are mostly limestone and dolostone with layers of marl in the upper Jurassic. In some places, there are loose sandy Quaternary sediments. However, the bed of the basin almost consists mainly of young alluvium, young terraces, and gravel fans. The climate of this area has been classified as warm and temperate. The average annual temperature in Garmabdasht is about 14.6 °C and annual rainfall is approximately 750 mm. Rainfall in the winter is more than summer in Garmabdasht and the most precipitation rate occurs in October. During the year, the average temperatures vary by 19.0 °C.

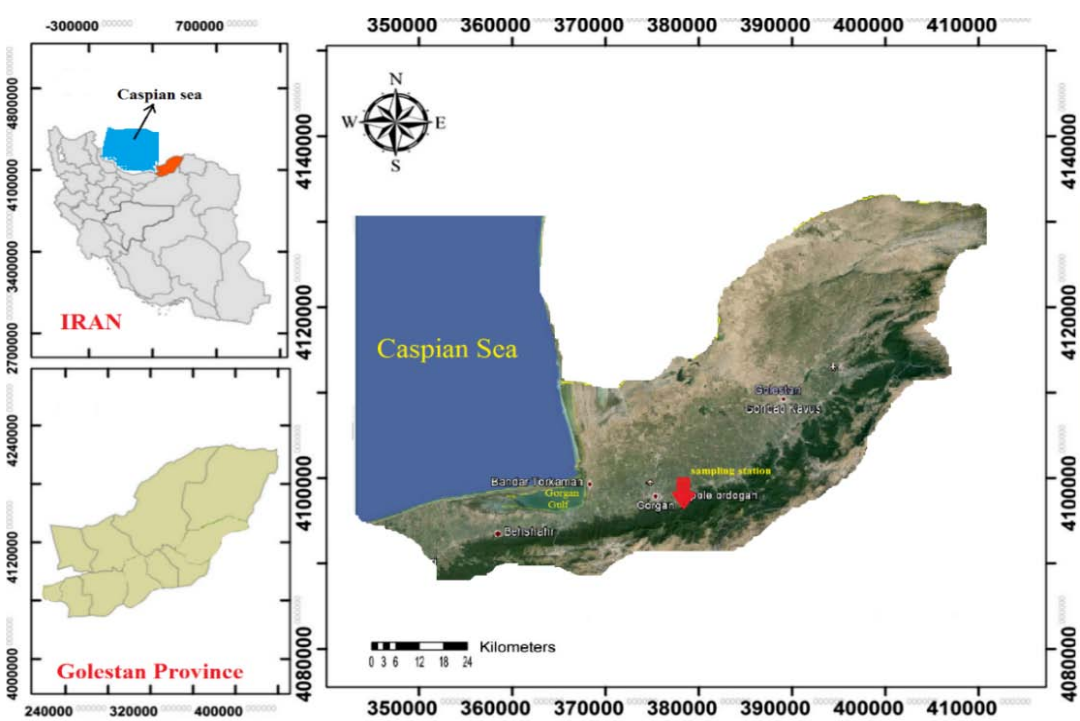

Fig. 1: Study area and sampling location

In this study, we used Pole-ordogah hydrometric station in Garmabdasht River. For examination of Garmabdasht water quality from 1986-2010, 241 samples were analyzed overall. Electrical conductivity (EC), total dissolved solid (TDS) and pH were measured by a water checker portable meter (hatch model HQ40D53000000). The bicarbonate (HCO3-) had been measured by the alkalinity measurement method. Sodium (Na+), potassium (K+), magnesium (Mg2+), calcium (Ca2+), chlorine (Cl-) and sulfate (SO42-) were measured by Graphite atomic absorption (furnace 4100) using standard methods.

In order to examine the classification of physicochemical parameters to achieve the Model, WHO (2006) recommendation as a worldwide standard and standard of Institute of Standards and Industrial Research of Iran (ISIRI) as local standard (Fallahzadeh et al. 2016) were used in this study. Since ISIRI values in most of the parameters are as same as WHO except for Ca and Na and also the local standard presents no standard for bicarbonate, EC, and potassium, WHO thresholds have been used for the model. The comparison of WHO and ISIRI has been presented in Table 1.

Table 1: Comparison threshold of parameters between WHO and ISIRI

Variable	WHO 2006	ISIRI 2016
pH	6.5-8.5	6.5-8.5
EC(μS/Cm)	1400	-
Cl (mg/l)	250	250
HCO_3(mg/l)	250	-
Ca (mg/l)	75	300
Mg(mg/l)	50	30
Na(mg/l)	50	200
K(mg/l)	10	-
SO_4(mg/l)	250	250

III. Results and Discussion

The pH is one of the most important variables in water quality assessment. Variation in pH may reveal the attendance of some sewage, particularly when it is continuously measured and recorded (Chapman 1996). The temporal Model of pH value from 1986 to 2010 has been demonstrated in Fig 2.a. As the Model indicates, most of the investigated samples are suitable in terms of pH (the green squares). Only from 1987 to 1989, especially in the first half of the year, some of the samples were acidic (the red squares).

The total dissolved solids (TDS) correspond to the filterable residue (Chapman 1996). For TDS, Hem (1985) has released a classification of 7 classes. Ideal drinking water (0-50, *very pale blue* squares), mountain spring and aquifers (50-100, *blue* squares), hard water (100-200, dark blue squares), marginally acceptable (200-300, *violet* squares), high TDS from tap water (300-500, *green* and *yellow* squares) and the contaminated level (>500, red squares). The temporal Model of TDS from 1986 to 2010 has been shown in *Fig 2.b*. As the Model shows, in most cases, high TDS from tap water is dominated. In some cases, TDS exceeded more than 500 which shows the contamination of TDS.

Calcium is easily dissolved from rocks rich in calcium particularly limestone and gypsum (Chapman 1996). Based on WHO recommendation, 75 milligrams per liter Ca is normal for water. The temporal Model of Ca from 1986 to 2010 has been illustrated in *Fig 2.c*. As the Model shows, more than 70 percent of samples are suitable (the *green* squares). But in some samples, especially in the second half of the year, calcium is over the limit (the *red* squares).

Chlorine takes the place of chloride in the solution (Chapman 1996). Based on WHO recommendation, 250 milligrams per liter Cl is normal for water. The temporal Model of Cl from 1986 to 2010 has been shown in *Fig 2.d.* The Model shows that all of the samples are less than authorized (the *green* squares).

Bicarbonate is the most common form of inorganic carbon usually found as a dominated ion between pH of 6 to 8.2. When the river basin consists no carbonate rocks, the HCO_3 is derived from soil CO_2 (Chapman 1996). According to WHO, up to 250 milligrams per liter HCO_3 is allowed for water. The temporal Model of HCO_3 from 1986 to 2010 has been shown in *Fig 2.e*. The Model shows that more than 75 percent of samples are suitable (the *green* squares). However, in some samples, especially in the last second season of 1992, HCO_3 is over the limit (the *red* squares).

Potassium with low concentration can be found in natural waters from rocks which consist of potassium. These rocks are relatively stable to weathering (Chapman 1996). Corresponding to WHO, 10 milligrams per liter potassium is allowed for normal water. The temporal Model of K from 1986 to 2010 has been demonstrated in *Fig 2.f.* The Model shows that most of the investigated samples are suitable in terms of K (the *green* squares).

Magnesium comes mainly from the weathering of ferromagnesian minerals, carbonate rocks and organometallic and organic matter (Chapman 1996). Based on WHO recommendation, 50 milligrams per liter magnesium is permissible. The temporal Model of Mg from 1986 to 2010 has been presented in *Fig 2.g*. As the Model shows, almost all samples (except one sample in 1995, the *red* square) are appropriate (the *green* squares).

All natural water sources include an unspecified number or amount of sodium. Increased concentrations of sodium in surface waters may come from sewage and industrial effluents (Chapman 1996) and it also may be derived from halite and silicate minerals. Based on the WHO standard, 50 milligrams per liter of sodium is permissible. In the temporal Model of Na from 1986 to 2010, similar to Cl, all of the samples are less than the permitted amount *(Fig 2.h).*

Sulfate occurs from the leaching of sulfur compounds and sulfate minerals such as gypsum and pyrite (Chapman 1996). Based on WHO recommendation, 250 milligrams per liter sulfate is permissible. According to the temporal Model of SO_4 from 1986 to 2010, similar to Cl and Na, all of the samples are less than the permitted amount *(Fig 2.i).*

The quality index can be used to assess water quality changes based on the annual survey. A water quality index is a simplified expression of a complex set of variables that is calculated by collecting some water quality measurements into one number (Chapman 1996). The IEI (Ion Enrichment Index) represents a value between -1 and 1 that has been developed to assess the trend of ion changes in the study area. The proposed index can be calculated by the following equation:

$$\text{Ion Enrichment Index} = \text{IEI} = \frac{I_k - I_0}{I_0}$$

Where:

I_k= is the total concentration of each ion

I_0= the ion background level (based on WHO (2006))

Four categories would be recognizable based on IEI:

- $-1 < \text{IEI} < -0.5$, very low enrichment, suitable, *green* squares;
- $-0.5 \leq \text{IEI} < 0$, moderate enrichment, good, *yellow* squares;
- $0 \leq \text{IEI} < 0.5$, significant enrichment, impermissible, *red* squares;
- $0.5 \leq \text{IEI}$, very high enrichment, harmful, *dark brown* squares.

Although the IEI has been initially developed for surface waters, it can be used for ground waters and sea waters.

In order to evaluate the ion contamination and enrichment with the passage of time, the temporal classification Model of IEI for each ion has been investigated *(Fig 3)*. As shown, these Models have shown perfect conformity with the temporal Model that is prepared based on the standards.

It is important to note that in the physicochemical temporal Model based on IEI there is a different category compared to the physicochemical Model based on the standard. For instance, the samples that are located in moderate enrichment and have been shown as *yellow* squares are good but these samples are more vulnerable than the others because these areas are at risk of passing the limit. In addition, the samples which have been shown in dark brown and are categorized in the harmful class, are different from the IEI Model. These samples actually represent the occurrence of a particular incident in a certain time interval.

As shown in *Fig 3*, the Model of Calcium and bicarbonate are likely and have many events which show moderate and sometimes significant enrichment. These enrichments may have been caused by the effect of geology and sedimentary rocks in the bed of the basin. For potassium and magnesium, based on IEI Model, there is one significant enrichment (October of 1999) and two very high enrichment events (April/2000 and June/2001). The only especial judgment which we can have for these events can be some guess about the source of these enrichments. As presented, the source of these enrichments for K and Mg were same and an especial factor controlled the solubility of these ions in natural water.

For the purpose providing a comprehensive Model of physicochemical parameters based on the index IEI, at any specific timeframe, the average IEI index of all the ions has been calculated. Then a temporal Model based on IEI has been examined. *Fig 4* has shown an IEI_{total} - temporal Model. As the Model shows, at all timeframes of the sampling, the IEI_{total} index is relatively good and less than the extent permitted. But for approximately 50 percent of the samples, the status is close to the latest limit permitted and is vulnerable.

For the purpose providing a comprehensive Model of physicochemical parameters based on the index IEI, at any specific timeframe, the average IEI index of all the ions has been calculated. Then a temporal Model based on IEI has been examined. *Fig 4* has shown an IEI_{total} - temporal Model. As the Model shows, at all timeframes of the sampling, the IEI_{total} index is relatively good and less than the extent permitted. But for approximately 50 percent of the samples, the status is close to the latest limit permitted and is vulnerable.

IV. Conclusion

This study has been focused on proposing a new index based on ions and examining temporal-physicochemical and temporal IEI Models in Garmabdasht River in the southern part of Golestan Province in Iran.

Indices are a simplified declaration of a compound set of variables that can be used for a variety of targets such as water quality information to the public and decision makers, planning tool for managing, evaluating changes in quality, identifying quality problems and assessing the performance of contamination (chapman 2006).

The temporal-physicochemical Model results showed that:

- In the pH, Cl, K, Mg, Na, SO_4 Model, most of the samples are less than authorized.
- In the Ca and HCO_3 Model, approximately more than 70 percent of the samples are suitable.
- The TDS Model shows that in most cases, high TDS from tap water is dominated.

In order to examine the ion enrichment, IEI for each ion has been proposed. For the purpose of evaluating IEI by the passage of time, the temporal-IEI Model has been developed. Results of this Model show better classification than the temporal-physicochemical Model because the vulnerable samples have been shown in this Model.

Results of the temporal Model based on IEI_{total} examined in order to give a comprehensive Model, indicates that all of the samples are relatively good and less than the extent permitted, but approximately half of the samples are vulnerable.

It should be noticed that if only one parameter presented the water quality exceeds the maximum limit, the water should not be used as drinking water. By using IEI_{total}, increasing one parameter would be covered by decreasing another parameter. With regarding this problem, we recommended using Temporal-Physicochemical Model of each parameter, Ion Enrichment Index for each parameter and IEE_{total} simultaneously to have the best judgment about the quality of water.

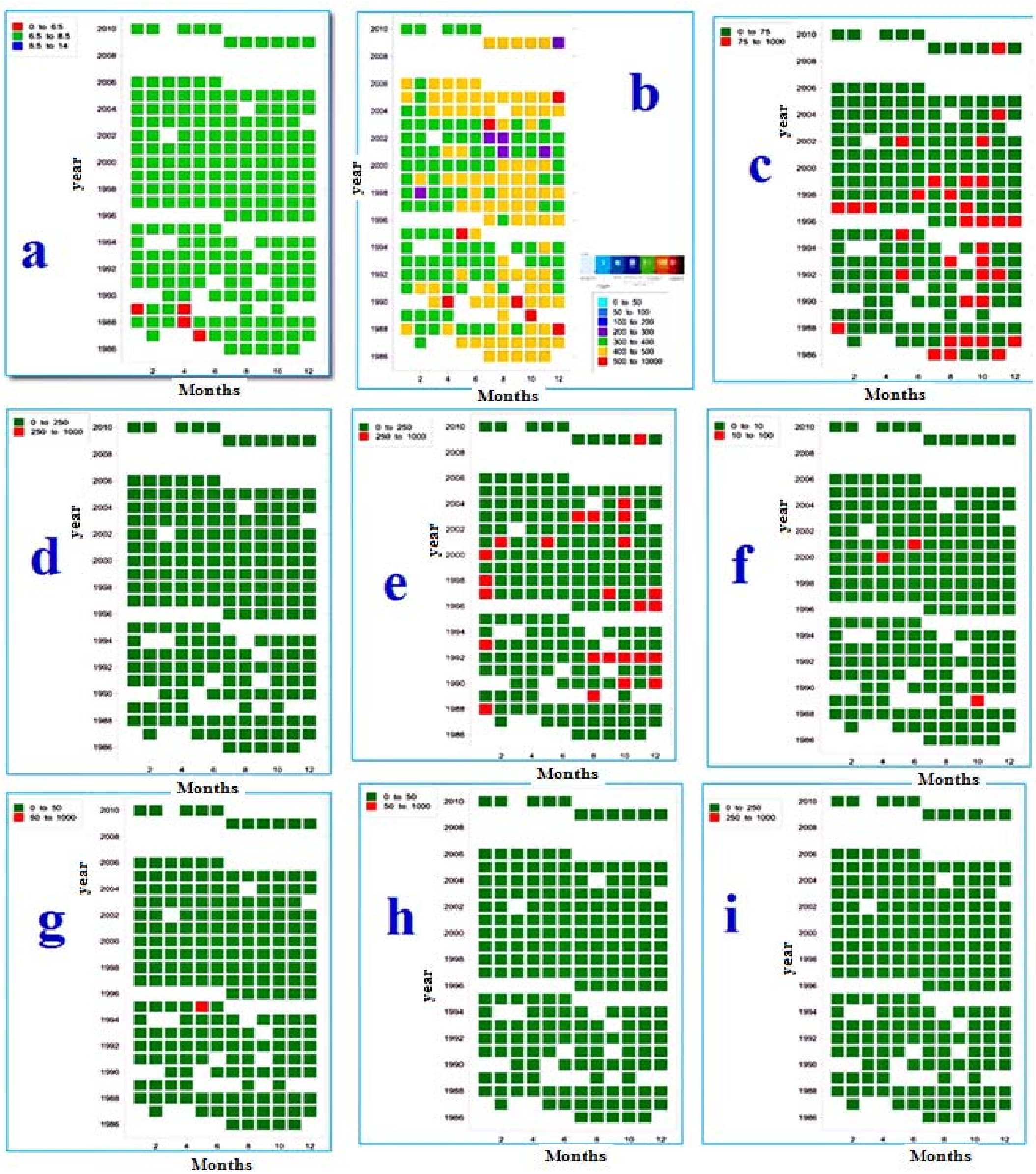

Fig. 2: Temporal-physicochemical pattern of Garmabdasht from 1986 to 2010; a) pH; b) TDS; c) Ca; d) Cl; e) HCO_3; f) K; g) Mg; h) Na and i) SO_4

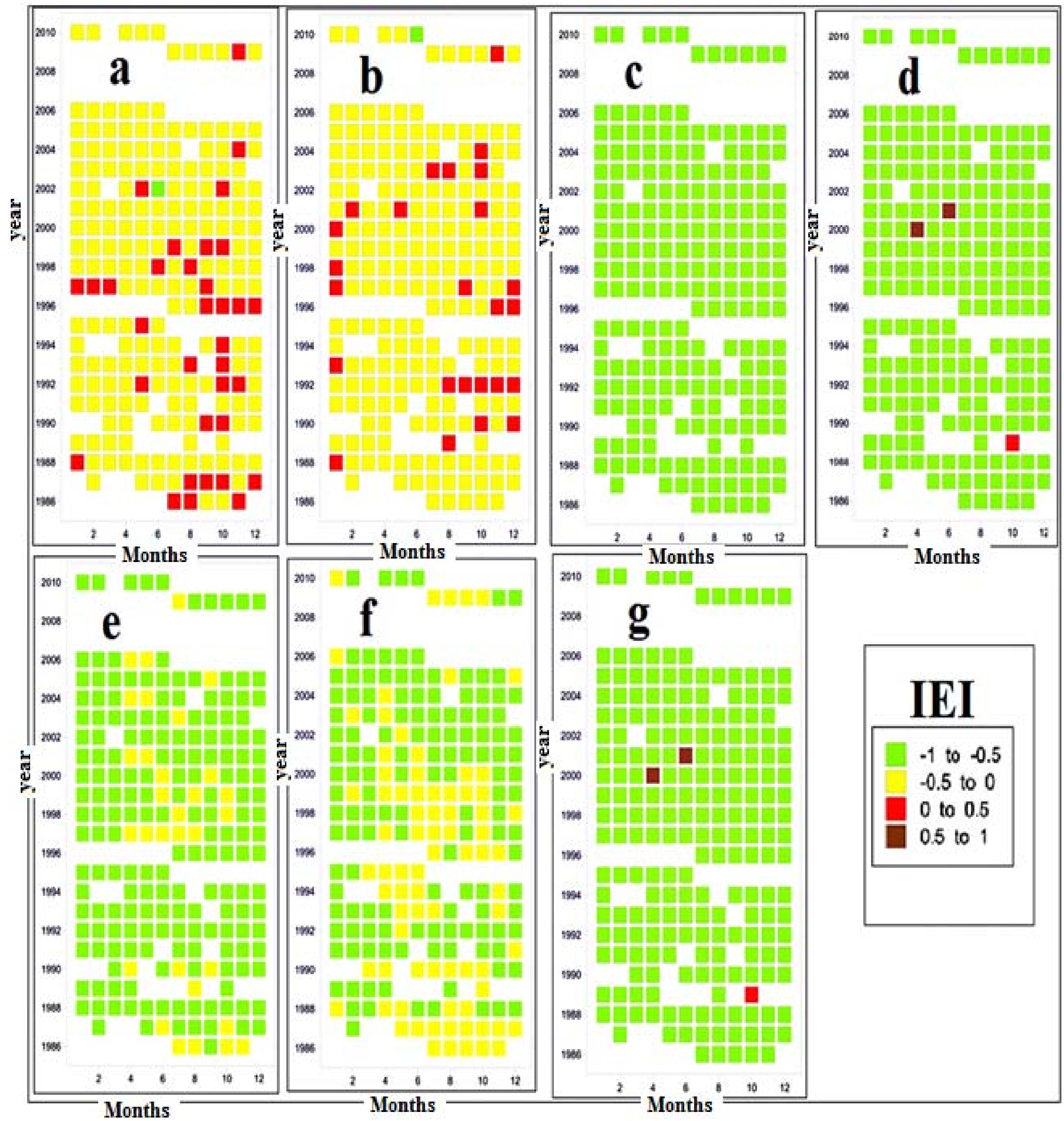

Fig. 3: Temporal pattern of Garmabdasht from 1986 to 2010 based on IEI; a) Ca; b) HCO_3; c) Cl; d) K; e) Na; f) SO_4 and g) Mg

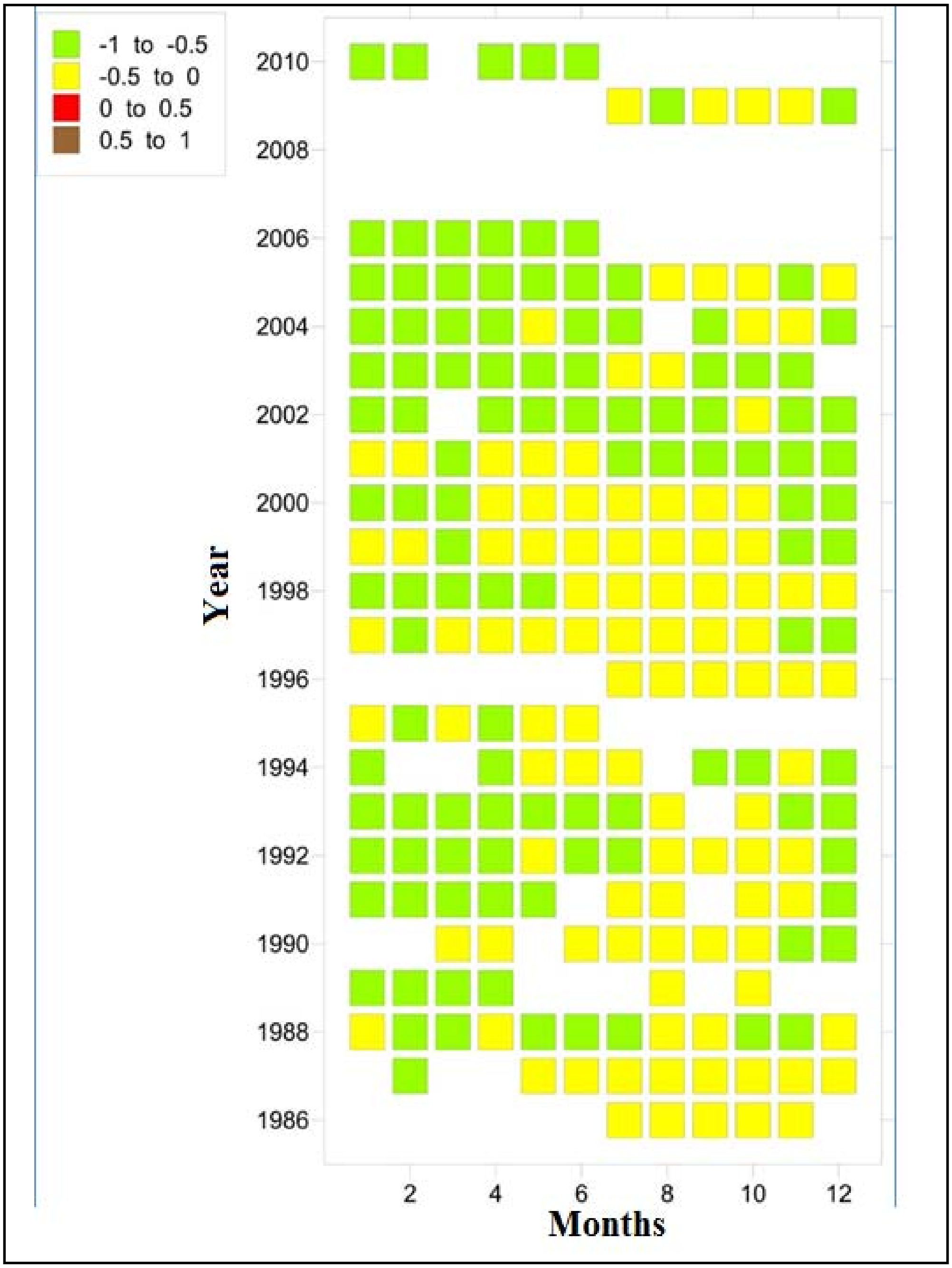

Fig. 4: Temporal - IEI_{total} pattern of Garmabdasht from 1986 to 2010

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