Chapter 2
Selection of Water Quality Monitoring Stations

Abstract Due to financial constraints and improper selection of water quality stations considering the objective of water uses, water quality monitoring network design is an efficient method to manage water quality. The most crucial part is to find appropriate locations for monitoring stations. In the past, most of water quality selection stations were subjective and the designs on the network had some human error. However, now there are several mathematical methods using experimental data for assessment of existing monitoring stations or designing new network such as Sanders method, multiple criteria decision making (MCDM) and dynamic programming approach (DPA) that developed by researchers. In the following chapter, after reviewing the historical background of developing and application of the methods, the theory of these methods was described in details. Finally, the application of the Sanders Method to design number of water quality monitoring stations in the Kārūn River which located in the south west of Iran was studied.

2.1 Historical Background

Allocation of the water quality monitoring site is the first and the significant step in the design of the water quality network. The importance of water quality network control concerning pollution causes creation of water quality stations in the network. However, finical constraints causes to decrease the number of water quality station in the network. Regarding optimizations of a number of monitoring stations some techniques were developed such as Sanders method, artificial neural network, Multi-Criteria Decision Method (MCDM) and Dynamic Program Approach (DPA). Some researches were carried out by Sharp (1970, 1971); Dandy (1976); Sanders (1983); Schilperoort and Groot (1983); Ward and Loftis (1986); MacKenzie et al. (1987); Woldt and Bogardi (1992); Harmancioglu and Alpaslan (1992); Hudak and Loaiciga (1993); Karemi (2002); Ozkul et al. (2003); Khalil and Quarda (2009); Noori et al. (2007); Karamouz et al. (2009); Khalil et al. (2011); Asadollahfardi et al. (2011). The DPA technique, which is a general method for maximizing and minimizing mathematical functions for solving a problem together with Multi-Criteria Decision,

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was introduced by Bellman (1957). Letternmaier et al. (1984) suggested an optimization method, which they used the DPA, for inspection of water quality station. They applied the technique for reduction of the number of stations in the urban water quality monitoring network. The results showed a reduction of monitoring stations from 81 to 47. The DPA was studied and extended by some researchers such as Harmancioglu et al. (1994, 2004) and Icaga (2005). Harmancioglu et al. (2004) applied the DPA on Gediz River in the West of Turkey for reduction of water quality monitoring stations. Icaga (2005) assessed existing water quality monitoring stations of the Gediz River applying the DPA for different water usage and allocated a different weight for indices of each water quality monitoring site. Cetinkaya and Harmancioglu (2012), applied the DPA for assessment of water quality monitoring stations. The results showed that the DPA was a suitable tool for optimization of the number of monitoring stations which are going to be remaining. Asadollahfardi et al. (2014) used the DPA for assessment of existing water quality of Sefīd-Rūd River in North of Iran. The results described that the DPA reduced the number of stations of the network.

As mentioned previously, there are numbers of methods for selection of stations. In this chapter Sanders, MCDM and dynamic approach is briefly described.

2.2 Sanders Method

The method proposed by Sanders et al. (1983) involves the identification of sampling reaches in a river basin (Macro location) when the intent is to allocate monitoring sites along the entire basin. According to Sanders et al. (1983), the objectives of the sampling must be defined prior to the actual design process.

The emphasis on water quality management efforts has recently been shifted from detection of stream standard violations to the assessment of overall trends in water quality because of various complications in compliance monitoring, such as intermittent or random sampling practices and incorrectly selected sampling locations. As a result, restrictions on effluent quality have become more significant than those on stream quality. In this case, a network developed for the assessment of trends must cover sampling points which will yield information characteristic of reaches of the river and in composite with other stations will yield information characteristic of the condition of the river system in general (Sanders et al. 1983). Sanders et al. (1983) proposed their method for site selection in a water quality monitoring network with the primary objective of detecting, isolating and identifying a source of pollution. Sanders et al. (1983) describe three approaches for macro location:

- Allocation by the number of contributing tributaries;
- Allocation by the number of pollutant discharges;
- Allocation by measures of BOD loadings.

These approaches, although they may produce a rather different system of stations, work pretty well in initiating a network when no data or very limited amounts of data are available. It must be noted that, by applying these methods, one may roughly specify the appropriate sampling sites. To pinpoint the locations more precisely, micro location and representative sampling considerations must be followed.

The first approach systematically locates the sampling sites so as to divide the river network into sections which are equal in respect to the number of contributing tributaries. The first stem involves stream ordering, where each exterior tributary or link contributing to the main stem of the river, (one which has no other tributaries or one with a certain minimum mean flow) is considered to be of the first order. Ordering is carried out along the entire river such that a section of the river formed by the intersection of two upstream tributaries will have an order described as the sum of the orders of the intersecting streams. At the mount of the river, the magnitude (order) of the final river section will be equal to the number of all contributing exterior tributaries.

Next, the river is divided into hierarchical sampling reach by defining centroids for each reach. The major centroid which divides the basin into two equal parts is found by dividing the magnitude of the final stretch of the river by two. Accordingly, the major centroid where a first hierarchy station is to be placed is located in that link whose magnitude is closest to:

$$M_{ij} = [(N_0 + 1)/2] \tag{2.1}$$

where M_{ij} = the first hierarchical location; with M = the magnitude (order) of the link, i = the hierarchical level of the station to be placed on that link, and j = the order of that station within the ith hierarchical level (e.g., M_{11} = the first station at the first hierarchical level and M_{12} = the second station of the same hierarchy). N_0 = the total number of exterior tributaries at the most downstream point of the basin where station M_{11} is placed M_{12} (Or the stream number closest to it) divides the total catchment area into two equal parts for which new centroids may be determined.

In the above procedure, it must be noted that a link determined at a given hierarchy does not necessarily have the value of $\mathrm{M_{ij}}$ because a link of that number may not exist. In this case, the link closest in magnitude is chosen as the centroid when this link is specified a sampling location is placed at its downstream junction. Although Sanders et al. (1983) located the station M_{ij} at the downstream point of the reach that has the corresponding stream order number, it may be allocated to any site along that reach, considering such local factors as accessibility of the site or the presence of a stream gauging station also; note here that the squared brackets in Eq. (2.1) indicate a truncation of the enclosed value to an integer value.

As noted above, M_{12} divides the total basin into two equal parts where new centroids may be determined for the upstream part, the first station with the second hierarchical order is found by which is the magnitude of the link that divides the region upstream of M_{12} into two equal areas with respect to their drainage density.

$$M_{21} = [\frac{M_{12} + 1}{2}] \tag{2.2}$$

Essentially Eq. (2.2) applies the same procedure as in Eq. (2.1) by replacing N_0 with M_{12}.

For the downstream portion of M_{12}, one can either renumber the tributaries, or alternatively, the centroid may be found as the location with an order closest to either:

$$M_{ij} = (M_d - M_u + 1)/2 \tag{2.3}$$

$$\mathrm{M}'_{\mathrm{ij}} = \mathrm{M_u} + \mathrm{M_{ij}} \tag{2.4}$$

where, i = the hierarchy order; j = the order of the station; M_d = the order where the basin is divided on the downstream side; M_u = the order where the basin is divided on the upstream side. This procedure locates the station at the second hierarchical level as M_{12} and M_{22}. So that's two more sampling locations are added to the system, which now has four stations altogether in the first and second hierarchical levels.

Next, new stations may be allocated upstream and downstream of both M_{21} and M_{22} to constitute stations at the third hierarchical levels. This is accomplished by applying the same procedure described in Eqs. (2.1–2.4). Eventually, four new locations will be designated at the third hierarchical level so that the network now comprises eight stations altogether.

Having specified third hierarchical stations, the same procedure is applied to select higher order hierarchy locations, if necessary. Here hierarchy levels indicate sampling priorities so that increasing hierarchies show decreased levels of sampling priorities. How far the hierarchical divisions should be continued depends on economic considerations and information expectations from sampling at each hierarchy.

In the second approach proposed by Sanders et al. (1983), the same procedure is used by cumulatively numbering the discharges from polluting sources as if they are exterior tributaries. Consequently, the sampling locations are determined as functions of populations and industrial activities. In both approaches, the sampling stations are to be placed at the downstream end of a river segment before an intersection.

2.3 Multiple-Criteria Decision Making (MCDM) Method

MCDM is applied in complicated decisions making processes. The differentiating feature of these methods is their application of more than one criterion. The models are divided into two main groups: First, Multiple Objective Decision Making (MODM) models and second, Multiple Attribute Decision Making models (MADM). MODM models are applied for design whereas MADM models are employed to select the best options. The MADM is defined by the following matrix (Table 2.1).

Table 2.1 Matrix of MADM

	X_1	X_2	X_3	....	X_n
A_1	r_{11}	r_{12}	r_{13}	....	r_{1n}
A_2	r_{21}	r_{22}	r_{23}	....	r_{2n}
A_m	r_{m1}	r_{m2}	r_{m3}	....	r_{mn}

$A_1, A_2, \ldots, A_m$, in decision making matrix D, indicate m predetermined alternatives (Such as sampling stations in this work), $X_1, X_2, \ldots, X_n$ show n attributes (such as population, area of basin, water qualitative parameters, …) to assess desirability of each attribute. The members of matrix describe the special values of jth attribute for jth alternative. The optimal solution for a MADM consists of the most suitable assumed alternative A^*.

$$A^* = \{A_1^*, A_2^*, \ldots., A_n^*\}$$

$$X_j^* = \max i\, uj\, (r_{ij}) \tag{2.5}$$

$$i = 1, 2, \ldots., m$$

A^* consists of the most preferable desirability of every existing alternative in decision (Asgharpoor 2004). The various steps of this method will be presented as follows.

2.3.1 Making Dimensionless

To compare various measurement scales (for various attributes), it is necessary to use a dimensionless method (Asgharpoor 2004). There are several techniques to make dimensionless (none missing), but the normal method is explained. First normality of data is checked using the Shapiro-Wilk test. If data is not normal, Box–Cox technique can be used for normality. Finally, Uniform Function is applied to unify and perform dimensions of data.

In Box–Cox method, it is necessary to estimate a value for λ, and then the following equation can be applied for normality.

$$y_i = \frac{x_i^\lambda}{\lambda}\, for\, \lambda \neq 0 \tag{2.6}$$

where y_i = normalized data, x_i = original data and λ = a value which we substitute in Eq. (2.6).

2.3.2 *Assessment of Weighting (Wj) for Attributes*

In the majority of MCDM problems, particularly the part of MADM, it is essential to be acquainted with the relative significance of existing attributes, considering the sum of them should be equal to 1, and this relative significance assesses the preference rank of each attribute compared with other attributes for specified decision. There are various methods of weighting in MCDM. Considering the experts' opinions and the existing conditions, it is selected and weighted parameters that have a specific significance in the standard and have a high significance in special consumptions and also parameters which are given a higher worth for water quality attributes.

The final stage of decision is ranking of stations using Simple Additives weighting method (SAW).

In the SAW method vector w (weights of significant attributes that obtained in previous) is assumed and suitable alternative A* is calculated as follows:

$$A^* = \left\{ A_i | \max \frac{\sum w_i r_{ij}}{\sum w_j} \right\} \tag{2.7}$$

And if $\sum w_j = 1$:

$$A^* = \left\{ A_i \,|\, \max \sum w_i r_{ij} \right\} \tag{2.8}$$

Final weights that were obtained in the previous part are used in this stage and multiplied to equalized and dimensionless values of MADM matrix, and are the calculated sum of the parameters in each line. Therefore, for each station, a number was obtained that can be our selection attribute and based on that the stations were specified.

2.4 Dynamic Programming Approach (DPA) Method

The DPA is one of most applicable technique which nowadays is applied for modeling of operation systems. The DPA is a method for solving the problems joint with the Multi-stage Decision. In this method concerning the characteristic of staging the problem, we solve the problem with n staging and single variable instead of solving the problem with *n* variables.

2.4.1 *The DPA Theory*

At the first stage, reduction of the network is achieved by dividing river catchment area to *N* (*K = 1, 2,… N*) Primary basin. This division should not be according to the hydrology of the basin. The characteristic of the catchment area such as topography, geology, meteorology, land uses, population density and rivers crossing each other may be as criteria for dividing a catchment area to primary catchment area. Each sub catchment area must have a minimum one water quality monitoring station (Harmancioglu and Fistikoglu 1999).

In each primary catchment area named K, P_K is the number of existing stations in that catchment area, and R_k is the number of selected stations in the primary catchment area named K.

Thereby, the numbers of the possible cases of stations selection can be determined which if during determination of possible combination of stations which they must remain in each sub catchment area; in this case all the catchment area of the river must be considered. Number of substitution combinations can be obtained from binomial distribution (Eq. (2.9)).

$$C(TP_N, TR_N) = \binom{TP_N}{TR_N} = \frac{TP_N!}{TR_N!(TP_N - TR_N)!} \tag{2.8}$$

where TP_N = the number of existing stations in all catchment area of the river, and TR_N = the number stations to be retained in all networks. When the catchment area is divided by N sub catchment area, K = 1,…. N, each primary catchment area has P_K of primary station which is part of total existing stations in all catchment areas (TP_N) (Eq. (2.9)) therefore:

$$TP_N = \sum_{K=1}^{N} P_K \tag{2.9}$$

where TR_N = the sum of the number of existing stations in each sub-basin Eq. (2.10). When TR_N = total number of stations to be retained in the basin; number of stations which must remain in primary catchment area K = R_K, which can be defined according to Eq. (2.10).

$$TR_N = \sum_{K=1}^{N} R_K \tag{2.10}$$

Consequently, number of feasible answers for each sub catchment area with availability of R_K can be determined by Eq. (2.11).

$$C(P_K, R_K) = \binom{P_K}{R_K} = \frac{P_K!}{P_K!(P_K - R_K)!} \tag{2.11}$$

where R_K = 0, 1, 2, …, P_K.

Therefore, the number of total combinations of catchment areas substitution in the K primary catchment area can be obtained by Eq. (2.12).

$$TASC_K = \sum_{R_K}^{P_K} C(P_K, R_K) = 2^{P_K} - 1 \tag{2.12}$$

where $TASC_k$ = the number of total combinations of substitution catchment area in the primary catchment area. The R_K in each primary catchment area depends on R_K of other primary catchment area (Eqs. (2.2–2.10)). Total number of substitution stations in all catchment areas will be TASC (Harmancioglu and Fistikoglu 1999).

$$TASC = TASC_1 \times TASC_2 \times \cdots \times TASC_N \tag{2.12}$$

Or

$$TASC = \prod_{K=1}^{N} TASC_K \tag{2.12}$$

The TASC will assume a very large number according to the amount of $TASC_K$. For solving this problem, Letternmaier et al. (1984) suggested the stream order number method for the limitation of combination of substitution stations in the primary catchment area.

2.4.2 Normalization and Uniformization Procedure

For comparison of different scale measurements, data should be Dimensionless, thereby, the converted indices elements (n_{ij}) were computed with dimensionless quantity. Several methods are available to change the quantity to dimensionless. If the data was not normal, Box–Cox method was used for normality (Eq. 2.6). Subsequently for uniformization and dimensions the uniform function was used.

$SR_{j(i)kl}$ = the original data, $SU_{j(i)kl}$ = the normal and uniform data for the station i and sub catchment k.

For each quantity of TR_N, it is necessary to determine the number of selected stations in each primary catchment area k, named R_K. Therefore, the selected stations are the stations at which their sum of normalized data ($SU_{j(i)kl}$) are maximized.

We indicate $SU_{j(i)kl}$ with $TS_{j(i)K}$ (Eq. (2.14)).

$$TS_{j(i)k} = \sum_{l=1}^{l_N} SU_{j(i)kl} \tag{2.14}$$

Where l_N = number of parameters in the station i and in sub catchment area k.

While the significance of the parameters differs when they are compared with each other; we use relative weight for each parameter concerning the objective of monitoring, and the Eq. (2.14) will be converted to Eq. (2.15).

$$TS_{j(i)k} = \sum_{l=1}^{l_N} W_l \times SU_{j(i)kl} \tag{2.15}$$

where, W_l = relative weight for parameter i.

By Eq. (2.15) can be obtained total(all) amounts of the parameters in primary catchment area k and in the station i. In each primary catchment area k, different selections of the stations which depends on R_k, and the amount of $TS_{j(i)k}$ in each station is different. Therefore, the calculations must be with the combinations which the amount of $TS_{j(i)k}$ will be maximized (Eq. 2.16).

$$MTS_{j(i)k} = \max TS_{j(i)k} \tag{2.16}$$

By determination of the TR_N, the RK options are the selections which have a maximum amount of $MTS_{j(i)k}$ (Eq. (2.17)

$$SMTS = \max \sum_{K=1}^{N} \sum_{i=1}^{R_K} MTS_{j(i)k} \tag{2.17}$$

Equation (2.17) has two dimensions for solving it, we applied the DPA.

The objective is to find the combination of the stations which the amount of $MTS_{j(i)k}$ will be maximized (Eq. 2.18). TR_N is counter with known amount.

The objective function is Eq. (2.18).

$$V = \max \sum_{K=1}^{N} \sum_{i=1}^{R_K} MTS_{j(i)k} \tag{2.18}$$

The constraints are as follows:

$$\begin{aligned} &\sum_{K=1}^{N} R_K = TR_N \qquad 0 \le R_K \le TR_N \\ &0 \le j(i) \le P_K, \qquad j(i) \ne j(h), i \ne h \end{aligned} \tag{2.19}$$

where j(i) = the number of stations in primary catchment area *K*. *V* = the objective function, *N* = total number of primary catchment area, R_K = the number of stations which are retained in the primary catchment area, i = an index of the station in k primary station, j(i) = numbers of index stations i in the k primary station, and P_K = the number of existing stations in the k primary station.

2.5 Application of Sanders Method

In a study, designing the number of water quality monitoring stations on the Kārūn River, Iran, was carried out. We applied the Sanders method on the basis of irrigation and drinking water quality indices. The specified sites were compared to the existing sites in the system and the matched stations to this scheme were selected. Water quality sampling was carried out on 20 stations by the Iranian Department of Environment (DOE) in Khuzestan Province during the years 1995–2005. (Table 2.2 and Fig. 2.1).

At the first step, the catchment area (Fig. 2.2) was divided into four sub-basins which were named A, B, C and D. Gotvand Dam to Band-e-Gheer, Dez Dam to Band-e-Gheer, Band-e-Gheer to the south of Ahvaz City and Darkhoveyn to the Persian Gulf were considered as sub-basins A, B, C and D, respectively. Water quality parameters including the Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) as degradable and Total Dissolved Solid (TDS) as the non degradable were selected which weighted by coefficients of 0.2, 0.3 and 0.5, respectively. The combined results of these coefficients were the basis of the evaluation and weighting of the amount of pollution discharged by each of the pollution sources. For this matter, the mass discharge of effluent BOD, COD and TDS along with their weighting percentage for each pollution source of all sub-basins were calculated (Tables 2.3, 2.4, 2.5 and 2.6). Then, by adding the number of entering branches, as presented in the Fig. 2.2, and allocation one of the number of the main branches of the river, the number of pollutants entering each pollution source was calculated.

As an example, for Pars Paper Factory in sub-basin B, BOD, COD and TDS weighting percentages due to their total values, are 19.87, 57.36 and 10.8. The pollution load of this factory is calculated as follows:

$$0.2(19.87) + 0.3(57.36) + 0.5(1.08) = 21.7 \approx 22$$

Table 2.2 Monitoring Station on the Kārūn River

Station number	Station name	Station number	Station name
1	Gotvand	11	Kārūn–Band-e-Gheer
2	Kārūn–Band-e-Mizan	12	Mollasani
3	Shotayt–Arab Asad	13	Zargan
4	Shotayt–Band-e-Gheer	14	Pol-e-panjom
5	Gargar–Shushtar	15	Ommotamir
6	Kargar–Band-e-Gheer	16	Darkhoveyn
7	Dez–Chamgolak	17	Saboon sazi
8	Dez–Ab-e-sheerin	18	Haffar
9	Dez–Mostoafi	19	Abolhasan
10	Dez–Band-e-Gheer	20	Choabadeh

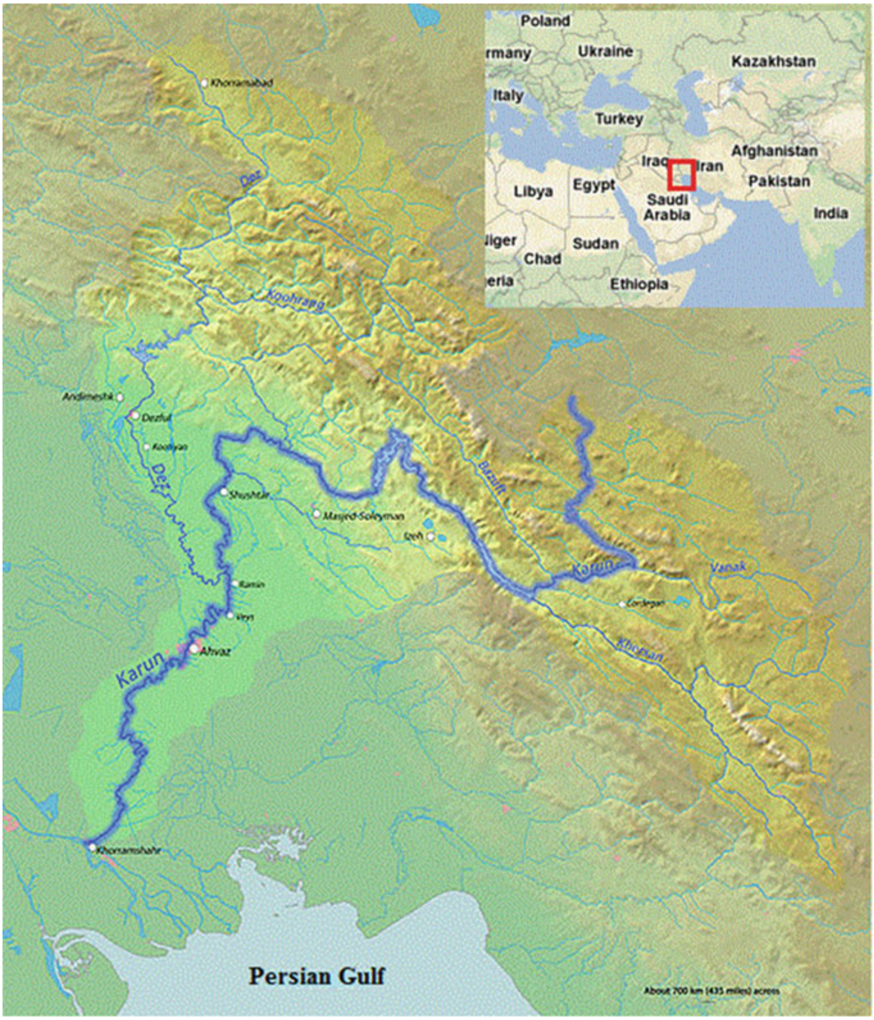

Fig. 2.1 The study area

Eventually, we determined the water quality of each station using the Sanders Method. The results described that the situation on stations located on Chobdeh, Abolhasan, Hafar, Soap Factory, Darkhoveyn, Omoltamir, Pol-e-Panjom, Zargan, Mollahasani and Kārūn-Band-e-Gheer was more crucial than others. On the other hand, the water quality of stations located on Gotvand and Dez-Chamgalk was more favorable. Totally the water quality of the Kārūn River for drinking and irrigation purposes in the sub-basins A and B is considerably better than sub-basins C and D (Table 2.7).

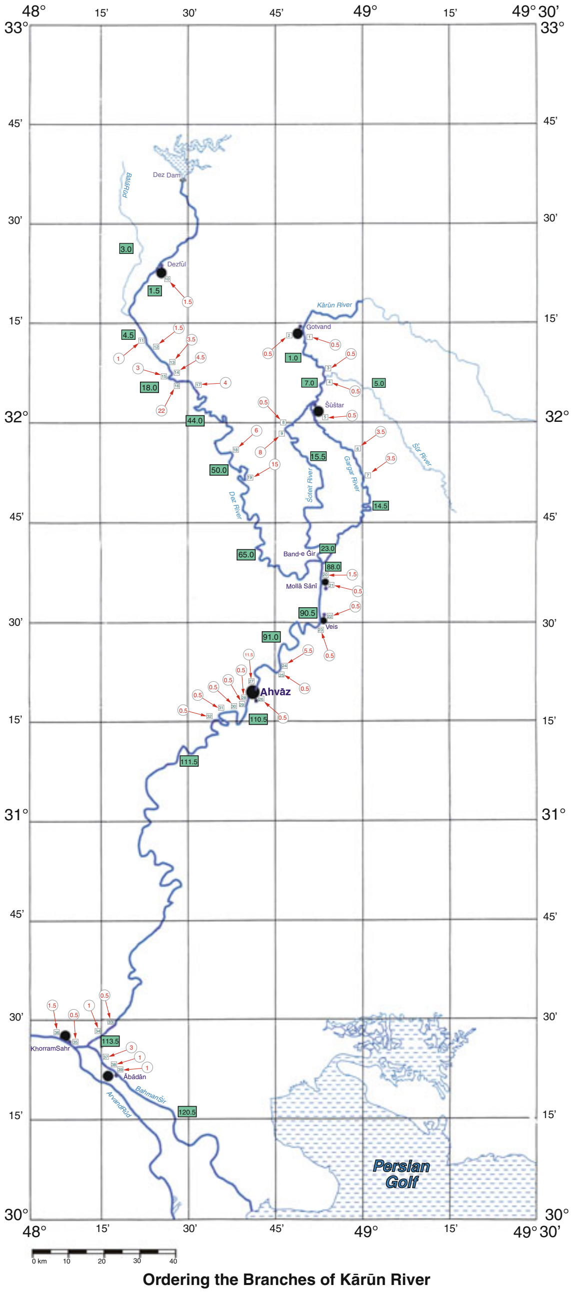

Fig. 2.2 Water quality sampling of the Kārūn River

Table 2.3 Amount of pollution load for sub-basin A

Pollution source location and number on the map	Weighting percentage BOD_5	Weighting percentage COD	Weighting percentage TDS	Final weighting
Kārūn sugar cane factory (2)	0.3	1	0.15	0.5
Fish cultivated field (7)	0.65	0.63	5.47	3.5
Kārūn sugar cane drainage (9)	3.4	7.3	10	8
Agheli drainage (8)	0.04	0.16	0.74	0.5
Janat Makan drainage GE (3)	0.015	0.01	0.31	0.5
Janat Makan drainage Gd (4)	0.02	0.02	0.21	0.5
Ghaghar agricultural drainage (6)	0.11636	0.5	5.98	3.5
Ghotvand (1)	0.596	0.21	0.15	0.5
Shoshtar (5)	1.097	0.57	0.19	0.5

Table 2.4 Amount of pollution load for sub-basin B

Pollution source location and number on the map	Weighting percentage BOD_5	Weighting percentage COD	Weighting percentage TDS	Final weighting
Dezful sugar factory (11)	2.9	0.63	0.25	1
Haft Tapeh sugar cane factory (15)	7.999	1.94	1.01	3
Pars paper production factory (16)	19.87	57.36	1.08	22
Saghari drainage (12)	0.4551	1.18	1.7	1.5
Solameh and agirob drainages (13)	1.21	3.86	3.82	3.5
Haft Tapeh drainage (14)	11.37	2.58	2.89	4.5
Meyanab drainage (18)	0.455	0.61	11.29	6
Kārūn sugar cane drainage (17)	0.96	0.84	6.67	4
Shoaybeh drainage (19)	0.2528	4.18	20.75	15

Table 2.5 Amount of pollution load for sub-basin C

Pollution source location and number on the map	Weighting percentage BOD_5	Weighting percentage COD	Weighting percentage TDS	Final weighting
Ramin power plant (23)	0.51	0.19	0.25	0.5
Zargan power plant (25)	0.081	0.05	0.19	0.5
Ahvaz sugar organization (24)	12.33	0.02	5.6	5.5
Sepanta factory (28)	0.045	0.01	0.06	0.5
Farsit factory (29)	0.0506	0.02	0.21	0.5
Ahvaz pipe production factory (30)	0.0976	0.02	0.07	0.5
National group factory (31)	0.6675	0.29	0.28	0.5
National group industrial plant (32)	0.1365	0.05	0.02	0.5
Ahvaz Khoramnoosh (26)	0.1766	0.18	0.3	0.5
Ahvaz slaughterhouse (20)	0.41	0.23	2.62	1.5
Mollahsani (22)	0.591	0.2	0.15	0.5
Vaes (22)	0.6118	0.38	0.12	0.5
Ahvaz city (27)	24.262	9.17	7.78	11.5

Table 2.6 Amount of pollution load for sub-basin D

Pollution source location and number on the map	Weighting percentage BOD_5	Weighting percentage COD	Weighting percentage TDS	Final weighting
Stris milk factory and Pasargad (33)	0.1264	0.05	0.34	0.5
Soap factory (34)	0.4955	1.4	0.24	1
Khorramshahr Khorram nosh soft drink production factory (35)	0.6068	0.05	0.04	0.5
Khorramshahr city (36)	2.4	0.97	1.26	1.5
Abadan refinery (39)	0.0	0.5	1.26	1.0
Abadan petrochemical production plant (37)	0.0	0.36	5.26	3.0
Abadan city (38)	1.03	0.5	0.84	1.0

Table 2.7 Score of water quality monitoring of the Kārūn River using Sanders method

Sub-basin	Location of station	Order
A	Gotvand	1
	Kārūn–Band Mizan	7
	Shotait–Arab asad	15.5
	Shotait–Band Gheer	15.5
	Ghargar–Shooshtar	7.5
	Ghargar–Band Gheer	14.5
B	Dez–Chamgalk	1
	Dez–Ab-e-sheerin	44
	Dez–Mostofei	50
	Dez–Band Gheer	65
C	Kārūn–Band Gher	88
	Mollahsani	90.5
	Zargan	91
	Pol-e-Panjom	110.5
	Omoltamir	111.5
D	Darkhoveyn	111.5
	Soap factory	113.5
	Hafar	115.5
	Abolhasan	118.5
	Chobdeh	120.5

2.5.1 Comment on the Application

Subjective selection of water quality monitoring may elevate a number of stations and may cause increasing errors in selection of the stations. As a result, the financial cost of installation and operation of the monitoring network can be increased. Therefore, mathematical methods which using experimental data such as Sanders method and dynamic programming approach may help to determine the locations and number of water quality monitoring stations, economically and correctly.

References

Asadollahfardi G, Asadi M, Nasrinasrabadi M, Fraji A (2014) Dynamic programming approach (DPA) for assessment of water quality network: a case study of the Sefīd-Rūd River. Water practice and technology 9(2):135–148

Asadollahfardi G, Khodadai A, Azimi A, Jafarnejad M, Shahoruzi M (2011) Multiple Criteria Assessment of Water Quality Monitoring System in Karoon River. J Int Environ Appl Sci 6 (3):434–442

Asgharpoor M (2004) Multi Criteria Decisions. Tehran university publication, Tehran

Bellman R (1957) Dynamic programming. Princeton University Press, Princeton

Cetinkaya CP, Harmancioglu NB (2012) Assessment of water quality sampling sites by a dynamic programming approach. J Hydrol Eng 17(2):305–317

Dandy GC (1976) Design of water quality sampling systems for network. Ph.D. Thesis, Massachusetts Institute of Technology, USA

Harmancioglu NB, Fistikoglu O (1999) Water Quality Monitoring Network Design. Kluwer Academic Publishers, Dordrecht, Netherland

Harmancioglu N, Alpaslan N, Alkan A, Ozkul S, Mazlum S, Fistikoglu O (1994) Design and evaluation of water quality monitoring networks for environmental management. Report prepared for the research project granted by TUBITAK, Scientific and Technical Council of Turkey, Project Code: DEBAG-23, Izmir (In Turkish)

Harmancioglu N, Cetinkaya C, Geerders P (2004) Transfer of information among water quality monitoring sites: assessment by an optimization method. In: 18th International conference informatics for environmental protection

Harmancioglu NB, Icaga Y, Gul A (2004) The use of an optimization method in assessment of water quality sampling sites. Eur Water 5(6):25–35

Harmancioglu NB, Alpaslan N (1992) Water quality monitoring network design: a problem of multi-objective decision making1. JAWRA J Am Water Resour Assoc 28(1):179–192

Hudak PF, Loaiciga HA (1993) An optimization method for monitoring network design in multilayered groundwater flow systems. Water Resour Res 29(8):2835–2845

Icaga Y (2005) Genetic algorithm usage in water quality monitoring networks optimization in Gediz (Turkey) river basin. Environ Monit Assess 108(1–3):261–277

Islamic Republic of Iran Meteorological Organization (1983) Climate Statistic http://www.irimo.ir. Accessed 15 Aug 2012

Karamouz M, Kerachian R, Akhbari M, Hafez B (2009) Design of river water quality monitoring networks: a case study. Environ Model Assess 14(6):705–714

Karemi M (2002) Design of river water quality monitoring system. MSc Theses, Amirkabir University, Iran (In Persian)

Khalil B, Ouarda T (2009) Statistical approaches used to assess and redesign surface water-quality-monitoring networks. J Environ Monit 11(11):1915–1929

Khalil B, Ouarda T, St-Hilaire A (2011) A statistical approach for the assessment and redesign of the Nile Delta drainage system water-quality-monitoring locations. J Environ Monit 13 (8):2190–2205

Letternmaier DP, Anderson DE, Brenner RN (1984) Consolidation of a stream quality monitoring network1. JAWRA J Am Water Resour Assoc 20(4):473–481

MacKenzie M, Palmer RN, Millard ST (1987) Analysis statistical monitoring network design. J Water Resour Plann Manage 113(5):599–615

Noori R, Kerachian R, Khodadai Drban A, Sakebaneya A (2007) Assessment of significance of monitoring stations rivers using analyses principal component and factor analys: a case study Kārūn River. J Wastewater, 18(63):60–69

Ozkul S, Centinkaya CP, Harmancioglu NB (2003) Design of water quality network in Gediz Basin using drainage and effluent discharge characteristic. In: Proceedings 1st national water engineering symposium. State Hydraulic Works (DSI) Publications, Ankara, Turkey, pp 215–227 (In Turkish)

Sanders TG, Ward RC, Loftis JC, Steele TD, Andrain DD, Yevjevich V (1983) Design of network for monitoring water quality. Water Resources Publication, Littleton, Colorado

Schilperoort T, Groot S (1983) Design and optimization of water quality monitoring networks. Delft Hydraulics Laboratory Delft, The Netherlands

Sharp W (1970) Stream order as a measure of sample source uncertainty. Water Resour Res 6 (3):919–926

Sharp W (1971) A topologically optimum water-sampling plan for rivers and streams. Water Resour Res 7(6):1641–1646

Ward RC, Loftis JC (1986) Establishing statistical design criteria for water quality monitoring systems: review and synthesis1. J Am Water Resour Assoc 22(5):759–767

Woldt W, Bogardi I (1992) Ground water monitoring network design using multiple criteria decision making ant) geostatistics1. J Am Water Resour Assoc 28(1):45–62

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