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A GENETIC ALGORITHM OPTIMIZATION MODEL FOR DIRECT PUMPING WATER SUPPLY INTAKES OPERATION

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Abstract: An optimization model for direct water supply intakes operation was created to maximize the rate of recovery of river bed, i.e. minimizing the effects pumping on river bed morphology. The model adopted constraints such as the water volume that should be pumped daily, minimum and maximum pumping intake capacity, and maximum time of pumping per day, while the objective function maximized is the rate of recovery of the river bed . The decision variables are selected as the pumping rate to river flow ratio, and the intake operation time to time of non-operation ratio. The model combines the Genetic Algorthim and the Artificial Neural Networks techniques to find the optimum solution. The application indicated that the required number of the randomly generated solutions and the number of cross over process for a stable optimum genetic algorithm solution are (100) and (1) respectively. Sensitivity analysis of the effect of number of cycles of operation and non-operation periods of the intake per day and the river flow indicates that these variables have no effect on the objective function.

Keywords: *River morphology, scouring, sedimentation, rate of recovery, artificial neural networks, genetic algorithm, optimization models, water intakes.*

1.0 Introduction

Sediment movement of the river bed near direct river intake structures is a complex problem that reduces the system efficiency and increases the cost of dredging and system maintenance. In case of power-plants using river-cooling water, sediment reduces the withdrawn capacity of the plant, causes damage to the pumping system and partial or full blockage at the entrance of intake. Sediment blockage may result in the stopping of the plant, Abd Al-Haleem, (2008). As water is abstracted through the intake, sediment is typically drawn towards the intake structure or point of diversion. Sediment may either be drawn into the intake structure or may be trapped behind it.

Many researches had been conducted concerning the problem that occurs in the water supply projects due to sediment withdrawal , Amin(2005), Zheng and Alsaffar(2000).

However, very little work had been done on the effect of direct water intakes operation on the river bed morphology. These intakes operation can affect the river bed morphology by creating considerable changes in the bed formation near the intake, and disturb the river as a system. This operation causes movement of sediments near the intake creating some sort of a hole in the vicinity of the intake. Part of the sediments moved due to pumping will be withdrawn with the pumped water, while the other part will move just downstream the intake where it deposited creating local sediment accumulation. The reduction in sediment downstream and increased erosion can damage important habitats (e.g. bank-side habitat) and habitats that depend on a supply of sediment from upstream reaches SEPA, (2008).

For a scientific and rational approach to different river problems and proper planning and design of water resources projects, an understanding of the morphology and behavior of the river is a pre-requisite, Ali *et al*.(2012). Rivers morphology is a field of science which deals with the change of river plan and cross sections due to sedimentation and erosion. In this field, dynamics of flow and sediment transport are the principal elements. The morphological Studies, therefore, play an important role in planning, designing and maintaining river engineering structures

These changes in the river morphology near the intake may disturb the natural river system. It may have effects on the natural flow and the ecosystem, Kaless *et al*(2011),Selander (2004). However, the river system will try to retain its natural properties when the disturbance created by the water intake operation stop. This is the recovery property of any natural system such as rivers. Many studies had been conducted concerning the river morphology changes, Scott and Jia(2005),Formann *et al*.(2007).

Khalaf *et al*. (2013) had developed an artificial neural network model that relates the rate of river bed recovery (defined by equation (1)), as the output variable with four input variables (d/w) the ratio of the extent of intake pipe in the perpendicular direction to the river flow direction to the width of river, (dsn/yn) the ratio of the intake strainer submergence depth to the normal depth of the rive,(Qr=Qp/QR) the ratio of the pumping rate of the intake to the river flow, and (tr=top/tnon) the ratio of the time of intake operation to the time of non-operation. The model correlation coefficient was (0.843). Many researches had been conducted concerning the application of the genetic algorithm in water resources engineering problems, Goldberg (1983), Goldberg (1991). Researches on this technique methodology were also conducted to the proper assignments of the schemes used and sizing of the genetic population, Goldberg(1989).

In this research it is intended to formulate an optimum operation model, that maximize the rate of recovery for an existing intake. This model can obtain the optimum pumping rate and the optimum ratio of the time of intake operation to the time of non operation. The model uses the genetic algorithm technique for the solution. Constraint adopted concern the required volume of water that should be pumped daily, the range of pumping capacity of the intake and the total time of operation non operation cycles per day.

2.0 Formulation of the Optimization Model

For the problem under study, the following optimization model was formulated in order to achieve the goal. It is worth mentioning here that this optimization model is an operational one, not a design one. This means that this model will optimize the operation of an existing intake with given ratio of the extent of the intake pipe along the river width to the width of river (d/w), given ratio of the strainer submergence depth to the river normal depth (dsn/yn), and given range of pumping capacity (Qp_{min},Qp_{max}). However this model can be used for optimum design and operation of intakes using assumed values for these variables.The objective function adopted herein is:

$$\text{Min. effect on river bed} = \textit{Maximize } Pr\,(Qr,\, tr,\, d/w,\, dsn/yn\,) = 1 - \frac{V_o - V_{non}}{V_o} \qquad (1)$$

Where:
Vo: is the volume of hole created after time of intake operation
Vnon: is the volume of hole after time of intake non operation.
Pr: is the rate of river self-bed recovery (rate of recovery)
d/w and dsn/yn: are auxiliary variables which are given for any existing intake or assumed by the designer for a proposed intake (are as defined before).
Qr, tr: are ratios of pumped flow to the river flow ratio (Qp/QR) and the ratio of time of operation to time of non operation (top/tnop) for each cycle of the intake operation, and represent the decision variables that the optimization model should find to maximize the rate of recovery (Pr).

The selected optimum Qr and tr should be subject to the following constraints:

$$\frac{\mathrm{Qpmin}}{\mathrm{QR}} \le \mathrm{Qr} \le \frac{\mathrm{Qpmax}}{\mathrm{Qr}} \qquad (2)$$

$$\mathrm{tr}_{\mathrm{min}} \le \mathrm{tr} \le \mathrm{tr}_{\mathrm{max}} \qquad (3)$$

Finding these optimum ratios, the optimum pumping rate Qp and the time of operation (top) , and time of non operation (tnop) of each cycle could be found as explained below.

For a given volume of water that should be pumped daily (V_P) in m^3, and for a river flow QR, and given pumping capacity range Qp_{min}, Qp_{max} , and the optimum flow ratio Qr one can find:

$$\mathrm{Top} = \frac{\mathrm{Vp}}{\mathrm{Qp}} \tag{4}$$

Top: is the total required time of pumping per day, where :

$$\mathrm{Qp} = \mathrm{Qr} * \mathrm{QR} \tag{5}$$

Then for a given optimum time ratio tr, and number of cycles of operation per day, nc:

$$\mathrm{Top} = \mathrm{nc} * \mathrm{top} \tag{6}$$

Multiplying and dividing equation (6) by tr(=top/tnop), to get:

$$\mathrm{Top} = \mathrm{nc} * \mathrm{top} * \frac{\mathrm{tr}}{\mathrm{top}/\mathrm{tnop}},$$ which yields:

$$\mathrm{tnop} = \frac{\mathrm{top}}{\mathrm{nc.tr}} \tag{7}$$

From which tnop is obtained, then top could be found by:

$$\mathrm{top} = \mathrm{tr.\ tnop} \tag{8}$$

and the total cycles time per day could be found by :

$$\mathrm{Tot} = \mathrm{nc}\,(\mathrm{top} + \mathrm{tnop}) \tag{9}$$

Additional constraints could be added easily according to the choice of operator; such as:

$$\mathrm{Tot} < 24\ hrs \tag{10}$$

$$\mathrm{nc} \le 3 \tag{11}$$

$$\mathrm{Top} \le 12\ \mathrm{hrs} \tag{12}$$

3.0 Genetic Algorithm Model Development

The formulated optimization problem can be solved using any non-linear optimization technique. The optimization problem is non-linear due to the non-linear relationship between Pr with the other variables as shown in equation (1), represented by the ANN model developed by Khalaf *et al*. (2013) for this purpose. However, the genetic algorithm model solution had proved to be effective, and can find the global optimum solution, hence, this technique was used in this research, Goldberg (1991), For obtaining the optimum values of the decision variables Qr and tr for the problem under consideration using the genetic algorithm technique, it needs the calculation of the fitness function (objective function), for a large number of randomly generated solutions, hence, the model was coupled with Khalaf *et al*. (2013) ANN model for this purpose. The following steps were used for this algorithm:

1) Generate an (np) number of feasible solutions in the form of four genes chromosomes as shown in Figure 1 below:

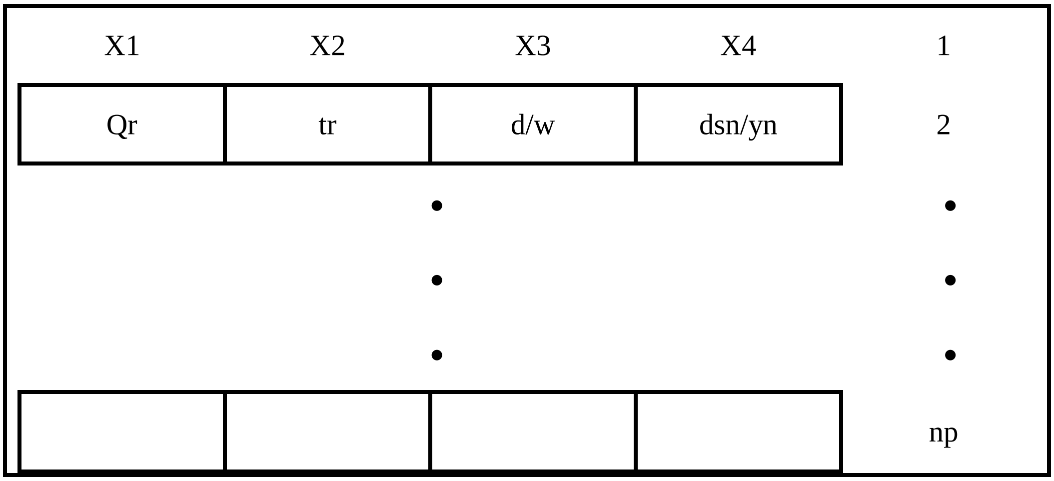

Figure 1: The chromosomes genes representation of the randomly generated feasible solution.

With the first two variables (decision variables), generated randomly and transformed to be feasible, i.e., within the constraints given by equations (2) and (3), respectively. The other two variables were kept constant for all the solutions as given for the existing intake and river properties. The required value of the number of population np (solutions) generated randomly for a stable optimum solution will be found upon application as will be shown later.

2) Obtain the fitness function (Objective function) of each solution generated in step(1) above using the Khalaf *et al*. (2013) developed ANN model and sort the solution according to the obtained objective function in descending order.

3) Apply the cross-over process with 100% cross-over probability Pc=100, in order to generate an (np) off springs population as shown in Figure 2 below.

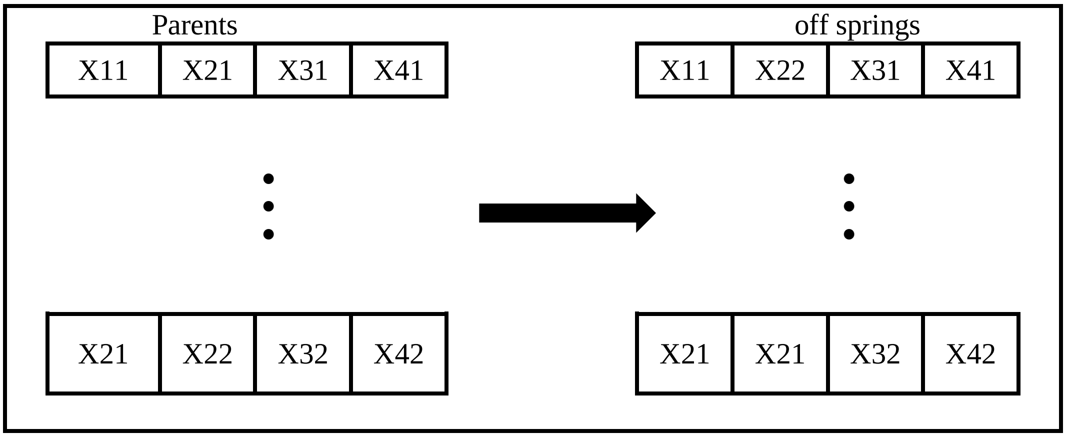

Figure 2: Cross over process of the genetic algorithm optimization technique.

4) Obtain the fitness function (objective function) for the off springs, and mix the two populations of the parents and off springs as (2np). Sort the new population in descending order of objective function Pr.

5) Omit the last np solutions and keep the first (np) solutions (the best) and repeat steps (3) to (5) for a selected number of iterations (it), which will be found upon application.

6) Apply a mutation process for the first selected (nm) solutions. This process includes a small changes in (Qr) and (tr) values to check if better optimum solution could be obtained.

4.0 Application of The Genetic Algorithm Optimization Model

In order to apply the optimization model developed above, a Mattlab code was written for this purpose and used for a given example as follows:

1) Required pumping volume per day, Vp=100000 m^3.
2) Available Qpumping capacity, Qpmin.=3 m^3/sec, Qpmax.=5 m^3/sec.
3) Available intake data and river flow and normal depth d/w=0.2625, dsn/yn=0.7, number of cycles nc=3, trmin=2 and trmax.=10.

Since the genetic algorithm technique starts with randomly generated solutions, sensitivity analysis is required for the two main parameters of this technique, the number of these solutions (population size) required for stable optimum solution, and the number of cross over process iterations. For each application there exists a minimum value for each of these two parameters that give a stable solution. If the selected values are less than those minimums then unstable optimum solution is obtained ,i.e.,for each run a new solution is resulted, and usually it is not the global optimum. Upon application of the developed optimization model to the data mentioned above, the minimum required randomly generated np solutions that gives a stable optimum solution values for this phenomena should first be obtained. Table 1 shows the results of three runs for each of some selected np values.

Table 1 : Effect of nP values on the stability of the optimum solution.

np	Run	Obj. Function	Qr	tr	Top (hr)	top (hr)	tnop (hr)	Qp m^3/sec
10	1	78.65	0.0136	9.89	6.813	2.27	0.23	4.07
	2	78.61	0.0102	8.12	9.076	3.03	0.373	3.06
	3	78.64	0.0136	9.34	6.83	2.28	0.244	4.09
20	1	78.63	0.0109	8.76	8.47	2.82	0.32	3.28
	2	78.64	0.0136	9.58	4.08	2.27	0.24	4.09
	3	78.65	0.0129	9.80	4.29	2.38	0.24	3.89
30	1	78.65	0.0147	9.94	6.28	2.09	0.21	4.42
	2	78.65	0.0111	9.90	8.05	2.69	0.27	3.45
	3	78.65	0.0147	9.74	6.31	2.10	0.22	4.39
50	1	78.65	0.0123	9.86	7.48	2.496	0.25	3.71
	2	78.65	0.014	9.92	6.51	2.170	0.219	4.27
	3	78.65	0.011	9.90	8.12	2.700	0.273	3.43
70	1	78.65	0.0147	9.862	6.281	2.093	0.212	4.422
	2	78.64	0.011	9.451	8.773	2.924	0.309	3.166
	3	78.65	0.0114	9.997	8.103	2.700	0.270	3.42850
100	1	78.65	0.0127	9.84	7.25	2.41	0.25	3.834
	2	78.65	0.0143	9.89	6.47	2.16	0.22	4.291
	3	78.65	0.014	9.87	3.98	2.21	0.22	4.190

Table 1 shows that a stable optimum solution, could be obtained when the np-value is 100. This stability is observed in the sense of obtaining a constant objective function, i.e., constant rate of recovery, with slight changes in the accompanied other variables. In order to find the required number of cross over process iterations (it), many runs were performed for the same data mentioned above, for (it)=1,2, and 3. It is observed that, only one iteration is enough as the results were the same even though the number of iterations was changed. This little effect of the number of iteration could be due to the limited number of decision variables (only two).

The following analysis is concerned with the sensitivity of some variables on the optimum solution of the phenomena under study, rather than that performed above which concern the genetic algorithm stability. All the following analysis will be done with np=100 and it=1, since these values were obtained as the genetic algorthim parameters that gives stable optimum solution for the phenomena under study.

In order to obtain the optimum schedule of operation, different runs were performed for the data of the above example. Table 2 shows the first three most optimum solutions. It is observed that even though slight differences in the objective function were observed, considerable changes were detected for the other variables. These three solutions were subject to a mutation process by making slight changes on the obtained optimum tr and Qr values. These mutations were found to have no effect on the optimum solution.

Table2 : Optimum solutions for np=100, (it)=1, and nc=3.

tr	Qr m^3/sec	Obj. function	Qp m^3/sec	Top hr	tnon hr	top hr	Total time of cycles (Tc)
1.990	0.013	77.56	3.94	7.05	1.18	2.315	10.60
2.969	0.013	77.99	3.90	7.13	0.80	2.370	9.54
3.942	0.011	78.23	3.47	8.01	0.68	2.670	10.04

Table 3 shows the effect of different values of the river flow (QR) on the optimum solution. It is shown that the model can observe the maximum possible objective function for all the values of QR, but with slightly different values of the other variables, except for the pumping flow Qp which was changed considerably as the river flow changes.

Table 4 shows the effect of different values of the number of cycles on the optimum solution. It is obvious that the maximum possible rate of recovery could be obtained by the model for different number of cycles by slightly changing the other variables.

Table 5 shows the effect of different values of the volume of water that should be pumped daily on the objective function. It is shown that the maximum possible rate of recovery could be obtained by changing the top values.

Table 3 : Sensitivity analysis for the effect of river flow on the optimum solution.

np	Run	QR m^3/sec	Obj. Function	tr	Top (hr)	top (hr)	tnop (hr)	Qp m^3/sec
100	1	600	78.65	9.88	8.57	2.86	0.29	3.24
	2	550	78.65	9.96	8.53	2.84	0.29	3.26
	3	500	78.65	9.87	6.04	2.01	0.20	4.59
	4	400	78.65	9.95	8.89	2.97	0.29	3.12
	5	350	78.65	9.86	7.21	2.40	0.24	3.85
	6	300	78.65	9.98	7.64	2.55	0.26	3.64
	7	250	78.65	9.95	6.97	2.32	0.23	3.97
	8	200	78.65	9.94	6.07	2.02	0.20	4.58
	9	100	78.65	9.94	7.14	2.38	0.23	3.89

Table 4 : Sensitivity analysis for the effect of number of cycles on the optimum solution.

nc	Run	Obj. Function	Qr	tr	Top (hr)	top (hr)	tnop (hr)	Qp m^3/sec
1	1	78.65	0.010	9.96	6.98	6.98	0.70	3.98
	2	78.65	0.013	9.96	6.07	6.07	0.61	4.58
	3	78.65	0.013	9.95	7.14	7.14	0.71	3.89
	4	78.65	0.013	9.86	7.22	7.22	0.73	3.85
2	1	78.65	0.011	9.99	8.26	4.13	0.41	3.36
	2	78.65	0.013	9.98	7.30	3.65	0.37	3.80
	3	78.65	0.011	9.93	8.41	4.21	0.42	3.30
	4	78.65	0.016	9.99	5.67	2.83	0.28	4.90
3	1	78.65	0.010	9.90	8.92	2.97	0.30	3.11
	2	78.65	0.010	9.71	8.82	2.94	0.30	3.14
	3	78.65	0.012	9.98	7.74	2.58	0.26	3.59
	4	78.65	0.012	9.97	7.56	2.52	0.25	3.67
4	1	78.65	0.013	9.86	6.75	1.69	0.17	4.12
	2	78.65	0.013	9.92	6.74	1.69	0.17	4.12
	3	78.65	0.010	9.92	9.02	2.26	0.23	3.08
	4	78.65	0.012	9.99	7.78	1.95	0.19	3.57

Table 5: Sensitivity analysis for the effect of the daily pumped volume on the optimum solution

Run	Vp	Obj. Function	Qr	tr	Top (hr)	top (hr)	tnop (hr)	Qp m^3/sec
1	25000	78.65	0.013	9.87	1.88	0.63	0.063	3.69
2	50000	78.65	0.014	9.96	3.27	1.08	0.11	4.30
3	75000	78.65	0.010	9.73	4.79	1.59	0.16	4.34
4	100000	78.65	0.010	9.97	6.69	2.23	0.22	4.15
5	150000	78.65	0.010	9.97	6.69	2.23	0.22	4.15
6	20000	78.65	0.010	9.99	16.51	5.53	0.55	3.34

5.0 Conclusions

Form the study conducted above the following conclusions can be deduced:

1) It was found that it is possible to obtain an optimum solution using the formulated optimization model and the genetic algorithm technique for the phenomena under study. Moreover there exists a maximum possible rate of recovery that the river can achieve.

2) The minimum number of populations that should be generated randomly to obtain a stable optimum solution for the phenomena studied should be 100, and only one iteration of cross over process is required. This stability is observed in the sense of obtaining a constant optimum objective function, i.e., constant rate of recovery even though the run of the program repeated frequently, with almost constant accompanied values for the other variables.

3) The maximum rate of recovery that could be obtained for a given intake data associated with the optimum operational model, is found not affected by the variation in river flow, this indicated a limited capability of the river for self-recovery, which means that the movement of bed during non- operational time, towards the created hole by the intake operation is limited. This is in accordance with the experimental data obtained by Khalaf *et al.* (2013), where when the time of operation increased over a certain limit, no increase in the rate of recovery was observed.

4) It is observed that a maximum rate of recovery could be observed by a certain time ratio and flow ratios, and almost a stable operation optimum schedule could be adopted for a given intake properties, hence it reflect easy operation for the intake operation authority.

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References:

Abd Al-Haleem, F.S.F., 2008,"Sediment Control At River Side Intakes", Ph.D Thesis, Egypt, Department Of Civil Engineering, Faculty Of Engineering, Minufiya University. Egypt.

Ali A. A., Al-Ansari N. A. And Knutsson S. , 2012 ," Morphology of Tigris River Within Baghdad City", Hydrology and Earth System Sciences., 16, pp.3783–3790.

Amin, A. M. A. , 2005,"Study Of Sedimentation At River Side Intakes", Ph.D Thesis, Minufiya University, Faculty Of Engineering, Civil Engineering Department, Shebin El-Kom.

Formann E., Habersack, H.M and Schober S.,2007," Morphodynamic River Processes And Techniques For Assessment Of Channel Evolution In Alpine Gravel Bed Rivers", Geomorphology Volume 90, Issues 3–4, 15 October (2007), pp.340–355.

Goldberg, D. E. and Deb, K., 1991, "A Comparative Analysis of Selection Schemes Used In Genetic Algorithms", Indian Foundations of Genetic Algorithms, G. J. E. Rawlins (ed.), pp. 69–93, Morgan Kaufmann Publishers .

Goldberg, D. E., 1983, "Computer-Aided Pipeline Operation Using Genetic Algorithms And Rule Learning", Doctoral Dissertation,. University Of Michigan, Ann Arbor, MI.USA.

Goldberg, D. E., 1989, "Sizing Populations For Serial And Parallel Genetic Algorithms", Proceedings of the 3rd International Conference On Genetic Algorithms, pp. 70–79.

Kaless G. , Mao L. , and Lenzi M. A ,2011," Regime Theories In Gravel Bed Rivers; Preliminary Comparison Between Disturbed Rivers Due To Atrophic Activities (Northeastern Italy) And Natural Rivers (Patagonia, Argentina)",Convegno Di Medio TermineDell’associazioneItaliana Di IngegneriaAgraria,Belgirate, 22-24 Settembre 2011,Memoria N.

Khalaf R.M., Al Suhaili R.H., and Al-Osmy S. A. T. ,2013, " Experimental and Artificial Neural Networks Modeling for Rivers Bed Morphology Changes near Direct Water Supply Intakes", Int. Journal of Engineering Research an d Applications, Vol. 3, Issue 6, Nov-Dec , pp.2111-2123.

Scottish Environment Protection Agency (SEPA), 2008 ,"Intakes And Outfalls" 1st Edition, October 2008.

Selander J. ,2004 "Influences On River Morphology In A Sediment-Dominated System". Chapter Four, pp.1-13, Mobogenie.Com/Download-Software.

Scott ,S. H. And Jia Y. ,2005," Simulation Of Sediment Transport and channel Morphology Change In Large River Systems", Us-China Workshop on Advanced Computational

Modeling In Hydro science and Engineering, The University of Mississippi ,September 19-21, Oxford, Mississippi, USA., PP.1-11.

Zaitsev, A. A., Belikov V.V. and. Militeev A. N. ,2004" Sediment Transfer Through The Fluvial System Using Computer Modeling For Regulation of Sediment Transport Under Hydraulic Structures On A Large River ", Proceedings of A Symposium Held In Moscow, August 2004, IAHS Publ. 288, pp.386-394.

Zheng, Y. and Alsaffar, A. M. ,2000," Water Intake Sediment Problems in Thermal Power Plants, ASCE, Doi: 10.1061/40517(2000)273 , pp. 1-8.