Particle Swarm Optimization applied to Multi-Reservoir Operating Policy in Inter-Basin Water Transfer System

Oussam LAASSILIA, Driss OUAZAR, Ahmed BOUZIIANE
Hydraulic Systems Analysis Laboratory
Mohammadia School of Engineers-EMI-Rabat, Morocco
oussama.laassilia90@gmail.com

Moulay Driss HASNAOUI
Water Resources Division
Water Department
Rabat, Morocco
hasnaouimd@gmail.com

***Abstract*—For many centuries, Inter-Basin Water Transfer (IBWT) projects have been adopted to mitigate the problem of the heterogeneous distribution of water resources. Thus, water transfers are usually carried out between reservoirs having surplus water toward deficitary reservoirs. Therefore, operating rules for managing those complex systems must taking into account satisfaction of local demand for donor reservoirs, then ensure an optimal water transfer that helps to cover demands in deficitary areas, all in avoiding unnecessary water spills. In view of this, the return to optimization methods is essential in order to elaborate an optimal model allowing to achieve all these objectives. This paper presents an overview of optimizing multi-reservoir operating rules in IBWT system using the heuristic Particle Swarm Optimization (PSO). The main aim of this study is to develop a Simulation-Optimization model in order to optimize operation of North-to-South Inter-Basin Water Transfer (NS-IBWT) project in Morocco.**

Keywords*—*Inter-Basin Water Transfer; Multi-Reservoir Operating Rules; Optimization-Simulation; Particle Swarm Optimization.

I. Introduction

Global demand for freshwater is increasing as climate changes, population grows, and water resources are being overexploited [1, 2, 3]. Therefore, water management is becoming increasingly a permanent purpose and a challenging task for decision makers. Thus, managing water resources requires planning, development, distribution, and optimal consumption of water resources [4]. Reservoirs were constructed to alleviate water shortage problem in areas via redistributing water resources with temporal variability and spatial heterogeneity [5, 2, 6]. However, local reservoirs are still not enough for areas where the demand for water outstrips the amounts that are generated within a river basin, so Inter-Basin Water Transfers (IBWTs) are needed to mitigate water supply pressure [7, 8, 9, 10, 11].

Situation in Morocco is not an exception. In fact, water resources, characterized by their scarcity and their spatial and temporal irregularity, are under increasing pressure. To deal with this stressful situation and to satisfy the future water needs, Morocco has adopted, since 2009, the idea of transferring surplus water from the north-west basins to the deficit basins in the center of the country. The chosen design of the NS-IBWT project consists in transferring water between six reservoirs of different dams, in service and projected, via 500 km of pipes, canals and galleries. The feasibility of this project is under study. Current data on the project design and its impact on the environment are encouraging. However, the point that remains ambiguous is the effectiveness and sustainability of the transfer project under extreme phenomena as floods and droughts. Therefore, optimization study of this project is very demanded.

II. State-of-the-Art

Reservoirs, as key components in IBWT projects, have essential influences on regulating and storing water resources to meet certain requirements [12]. Nevertheless, the coordinated operation of multiple-reservoir systems is typically a complex decision-making process involving many variables, many objectives, and considerable risk and uncertainty [13]. Lin and Rutten [14] added that management of a multi-reservoir system is complex due to the curse of dimensionalities, nonlinearities and conflicts between different objectives.

A real-world inter-basin water diversion model would be complicated because of uncertainties in both water availability and water demand. Therefore, it is necessary to derive reservoir-operating rules because of limitations on inflow forecasting techniques [15, 16]. In fact, the reservoir operating rule curves represent a guiding tool for managing the water resource systems in order to afford water for all users with minimal shortages and higher protection of the downstream from floods [17]. For single reservoir or some simple systems, suitable rule curves can be found manually by experts or through simulation models [18]. However, it becomes substantial challenging when come up against large-scale interconnected reservoir systems. There are variety of methods can be used to derive reservoir operating rules, among which the simulation-optimization are one of the most efficient methods.

Optimization in design, planning and implementation of water resources systems have always been an intensive research area (see [19]). Application of optimization techniques for determining the optimal operating policy of reservoirs is a major issue in water resources planning and management. Thus, optimizing reservoir operations incorporate allocation of resources, development of stream flow regulation strategies, operating rules and real-time release decisions in its bodily constitution [5].

Optimization of IBWT projects have been discussed in a vast of literatures [20]. Jain et al. [21] carried out long-term simulation for integrated operation of the reservoirs in a large IBWT system in India and finally determined the water diversion capacity of each basin. Sadegh et al. [22] suggested a water diversion capacity of 240 Mm3/year based on the results of optimal allocation of inter-basin water resources. Salim [23] studied the optimization of a multi-reservoir system in interaction with time and space, by stochastic dynamic programming and simulation. Zhu et al. [9] optimized the regulation rule and diversion flows of the donor reservoir in an inter-basin water diversion system. Rani et al. [24] presented a set of linked optimization models for development of an optimal inter-basin water transfer policy. Gu et al. [6] has established a simulation-optimization of Multi-Reservoir Operation in IBWT System in China. Then, they proposed a set of water transfer rule curves to determine when, where and how much water should be diverted from each donor reservoir.

In the past, optimization problems have been solved by using mathematical methods as Linear Programming (LP), Non-Linear Programming (NLP), Dynamic Programming (DP) and Quadratic Programming (QP), in addition to simulation techniques [25, 26, 27, 28]. Therefore, optimization methods, such as Successive Linear Programming (SLP) [29, 30], Stochastic Optimization (SO) [31, 32], Progressive Optimization Algorithm (POA) [33, 34, 35] and Heuristic Algorithm (HA) [36, 37, 38], are designed to prevail over the high-dimensional, nonlinear, and stochastic characteristics. Among them, Particle Swarm Optimization (PSO). So far, optimization methods have been implemented for both planning purposes and for real time operation [5].

First introduced by Kennedy and Eberhart [39] and developed by Engelbrecht [40], PSO, as a stochastic Evolutionary Algorithm (EA), is proposed to model the intelligent behaviors of bird flocking and fish schooling [41, 42]. Similar to Genetic Algorithms (GAs), PSO can be classified as a bio-inspired paradigm [43]. Flexible operators, relative simplicity, absence of gradients, high speed of convergence and easily found solutions to mixed integer and combinatorial problems are some of outstanding advantages of PSO [4]. Ho [44] explained that PSO, similar to other EAs, works with a population referred to as a swarm and each individual is called a particle, each particle "flies" over the search space to look for promising regions according to its own experiences and that of the group. Consequently, the sharing of social information takes place and individuals profit from the discoveries and the previous experiences of all other particles during the search. As with other EAs, PSO has the ability to search over a wide landscape around the better solutions [44].

Mathematically, given a swarm of N_{popsize} particles, each particle i ($i \in \{1, 2, \ldots, N\text{popsize}\}$) is associated with a position vector $x_i = (x^i_1, x^i_2, \ldots, x^i_D)$ (D is the number of decision parameters of an optimal problem) which is a feasible solution in an optimal problem. Let the best previous position p_{best} memorized in P_{best} that particle i has ever found to be denoted by $p_i = (p^i_1, p^i_2, \ldots, p^i_D)$ and the group's best position ever found by the neighborhood particles of the i^{th} particle (g_{best} memorized in G_{best}) is $g_i = (g^i_1, g^i_2, \ldots, g^i_D)$ At each iteration step k+1, the position vector of the i^{th} particle $x_i(k+1)$ is updated by adding an increment vector $\Delta x_i(k+1)$, called velocity vi(k+1), as follows:

$$v^i_d(k+1) = v^i_d(k)+c_1r_1(p^i_d - x^i_d(k)) + c_2r_2(g^i_d - x^i_d(k)) \qquad (1)$$

$$v^i_d(k+1)= \frac{v^i_d(k+1).v^{max}_d}{|v^i_d(k+1)|}, \; if \; |v^i_d(k+1)|>v^{max}_d \qquad (2)$$

$$x^i_d(k+1) = x^i_d(k) + v^i_d(k+1) \qquad (3)$$

Where c_1 and c_2 are two positive constants, r_1 and r_2 are two random parameters which are found uniformly within the interval [0, 1], and v^{max}_d is a parameter that limits the velocity of the particle in the d^{th} coordinate direction. This iterative process will continue swarm by swarm until a stop criterion is satisfied, and this forms the basic iterative process of a PSO algorithm. Moreover, on the right hand of (1), the second term represents the cognitive part of PSO as the particle changes its velocity based on its own thinking and memory. The third term of (1) corresponds to the social part to enable the particle to modify its velocity based on the social-psychological adaptation of knowledge. PSO is conceptually very simple, and can be readily implemented in a few coding lines. It requires only primitive mathematical operators and very few algorithm parameters need tuning [44].

Current research on PSO mainly focuses on algorithmic implementations, improvements and engineering applications and has revealed many interesting findings. Ye et al. [45] proposed a novel multi-swarm Particle Swarm Optimization with Dynamic Learning Strategy (PSO-DLS). Chen et al. [46] proposed a Dynamic Multi-Swarm Differential Learning Particle Swarm Optimizer (DMSDL-PSO), inspired by the principle of hybrid strategy as one of the main research directions to improve the performance of PSO. Lynn et al. [47] carried out a comprehensive review of population topologies developed for PSO and Differential Evolution (DE). Machado-Coelho et al. [48] proposed a method for solving constrained optimization problems, using Interval Analysis (IA) combined with PSO, in order to reduce constrained optimization to quasi unconstrained one. Chen et al. [49] proposed a Particle Swarm Optimization algorithm with two Differential Mutation (PSOTD) based on novel structure with two swarms and two layers (bottom layer and top layer). Investigated on benchmark problems, Kiran [50] proposed a new update mechanism for Particle Swarm Optimization based on normal distribution. Furthermore, the proposed model is compared with the state-of-art variants of PSO algorithm.

PSO algorithm shown also great potential for solving difficult design problems in different engineering disciplines, such as vibration control [51], reuse water network [52], resource allocation [43], inverse modeling [53], conflict resolution [54] etc.

PSO has also powerful advantages for the efficiency and accuracy of optimal operations for large-scale multi-reservoirs [55, 56, 57]. Shourian et al. [58] presented a methodology for optimized design and operation of the upstream Sirvan basin in Iran. The model proposed integrates MODSIM generalized river basin network flow model with Particle Swarm Optimization (PSO) algorithm. Guo et al. [59] has developed a bi-level model and a set of water-transfer rule to solve the multi-reservoir operation problem in inter-basin water transfer-supply project using PSO algorithm. Zeng et al. [60] proposed a new water transfer triggering mechanism for multi-reservoir system to divert water from abundant to scarce regions with a constant diversion flow in an inter-basin water transfer-supply project, using an Improved Particle Swarm Optimization algorithm (IPSO) with a simulation model. Wang et al. [20] applied the Quantum-behaved Particle Swarm Optimization (QPSO) algorithm to develop operating rules that consider both water transfer and water supply of water distribution system simultaneously for guiding the operation of multi-reservoir system in bidirectional IBWTS system. Peng et al. [34] has employed a coarse-grained parallel PSO algorithm with a simulation model for effectively deriving the operating rule curves (water-transfer and hedging rule curves) applied to the North-line IBWTS in China. More recently, the authors proposed three multi-core Parallel Particle Swarm Optimization (PPSO) algorithms to optimize the joint operation model for inter-basin water transfer-supply systems (IBWTS) Peng et al. [61]. Wan et al. [62] provided tri-level programming model for multi-reservoir optimal operation in inter-basin transfer-diversion-supply project. Particle swarm optimization based on Immune Evolutionary Algorithm (IEA-PSO) is adopted for optimizing the decision variables. Nevertheless, Wan et al. [12] proposed the Progressive Reservoir Algorithm-Particle Swarm Optimization (PRA-PSO) method based on the principle of Progressive Optimization Algorithm (POA). Then, the authors tested its practicability through a case study of complex multi-reservoir system operation in China. Anzab et al. [4] presented a simulation-optimization model by linking Water Evaluation and Planning System (WEAP) to Particle Swarm Optimization (PSO) algorithm for optimal design and operation of an IBWT in Iran. In the same context, Mousavi et al. [63] proposed a Simulation-Optimization (SO) framework for reliability-based optimal sizing, operation, and water allocation in the Bashar-to-Zohreh inter-basin water transfer project. The SO framework linked the water evaluation and planning system (WEAP) simulation module, benefiting from fast and single-period linear programming, to the Multi-Objective Particle Swarm Optimization (MOPSO) for multi-period optimization.

III. MULTI-RESERVOIR OPTIMIZATION OPERATION MODEL FOR N-S IBWT IN MOROCCO

Multireservoir operating policies are usually defined by rules that specify either individual reservoir desired (target) storage volumes or desired (target) releases based on the time of year and the existing total storage volume in all reservoirs [13]. Nonetheless, the rule curves optimization for complex inter-basin multi-reservoir operation is a typical highly non-convex, nonlinear function characterized by many constraints and local maxima, and may be discontinuous and non-differentiable because the exact mathematical expression of water supply process is unknown [12].

A. *Joint Operation Policy For Complex IBWT System*

For multi-reservoir water-supply operation, many classical operating rules such as the pack rule, the space rule and the New York City rule (NYC rule) have been applied widely for a long time [64]. Both the space and the NYC rules attempt to avoid the situation of having some reservoirs spilling while the others remain unfilled [13]. El Harraki et al. [17] presented some examples of operating rules or constraints, defined by experience or by simulation and applied for reservoir or system of reservoirs in Morocco, as maintain an empty space in the reservoir in order to protect from floods, maintain a stock of water for fulfilling municipal and industrial demand for two years, and respect a maximum discharge at the downstream. However, the combination of high-dimensional, multi-peak and multiple constraints makes it incredibly difficult to obtain the optimal rule curves for multi-reservoir operation.

B. *Hedging Rule*

Hedging rule curves are defined by Wan et al. [12] as guidance on reservoir release, consistent with certain inflow and existing storage. Hedging rule curves and rationing factors (a, b, c, d) for each water demand used in this paper are illustrated in Fig. 1 and Table 1.

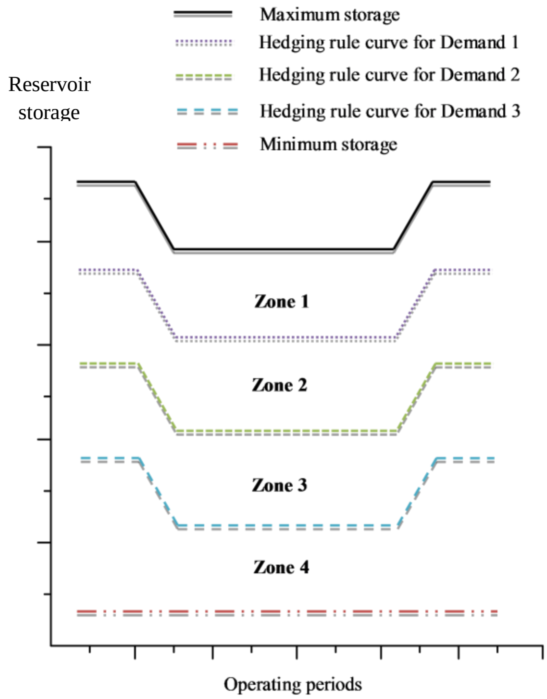

Fig. 1. Water supply hedging rule curves

TABLE I. WATER SUPPLY RULE IMPLIED BY RULE CURVES

Reservoir storage	Demand 1 (D1)	Demand 2 (D2)	Demand 3 (D3)
Zone 1	D1	D2	D3
Zone 2	D1	D2	c.D3
Zone 3	D1	b.D2	d.D3
Zone 4	a.D1	b.D2	d.D3

C. *Optimization Operation Model For N-S IBWT System*

A schematic diagram of the N-S IBWT system is given in Fig. 2. The transfer that will start from the projected dam Beni Mansour (BM, Laou basin) goes to the dam of Oued el Makhazine (OM, Loukkos basin), transferred water will then continue his way to the dam reservoir of Sidi Mohammed Ben Abdellah (SMBA, Bouregreg basin) with two water intakes from the Sebou basin; the first from the projected dam Kodiat Borna (KB) and the second from the Garde Sebou dam (GS). Subsequently, the transferred volume will be transported to the al Massira dam (2nd largest dam in Morocco with a capacity of 2.7 Bm3) (Oum Errbia basin). The volume transferred is estimated at 860 Mm^3/year [65]. According to the water transfer rule, OM and SMBA play the role as the donor reservoir as well as the recipient reservoir. Thereby, it makes the problem more difficult in finding the proper decision set.

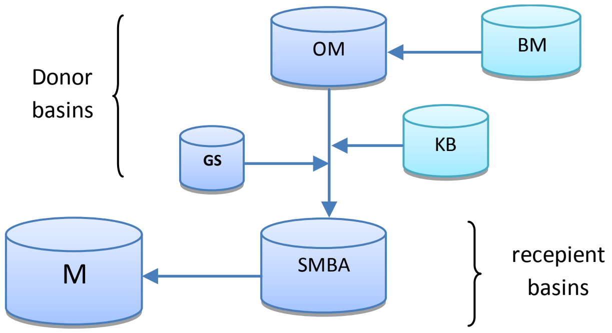

Fig. 2. Schematic diagram of N-S IBWT system

Water transfer rule directs the system manager on what conditions to divert water from donor to recipient reservoirs according to the relative position between the active storage of each individual reservoir and its own water transfer rule curve. Given that the main purpose of water transfer is to alleviate water scarcity in recipient regions and avoid great waste of diversion water, two indices are widely used by authors and adopted in this paper to optimize this complex IBWT system: reliability and water spill.

The reliability of water supply system is defined as the probability that system over given period is in a satisfactory state. Practically, it represents the percentage of years or months with the amount of water supply equaling to or exceeding the water demand. According to Gu et al. [6], this index can be expressed as:

$$Rel = \frac{1}{n}\sum_{k=1}^{n}(1 - x_k) \qquad (4)$$

Where x_k is an indicator variable which takes value 1 if water demand in month k is not satisfied; otherwise 0, and n is the total number of months. Higher value of Rel means the system is more reliable.

The objective function of this optimization operation can be expressed as follows:

$$Min : F = w_1 \sum_{i=1}^{6} \sum_{j=1}^{3}\left(1 - Rel_{ij}\right) + w_2 \sum_{i=1}^{6} \frac{SP_i}{N_i} \qquad (5)$$

Where Rel_{ij} is the reliability for reservoir i and user j, SP_i is the amount of annual average water spills (Mm^3/year) for reservoir i, Ni is the capacity (Mm^3) of reservoir i, w_1 et w_2 are weighting factors (with $w_1 + w_2 = 1$).

Model constrains are shown as follows:

$$S_i^{min} \leq S_i \leq S_i^{max} \qquad (6)$$

$$0 \leq T_{i,t} \leq T_i^{max} \qquad (7)$$

- For donor reservoir:

$$S_{i,t} = S_{i,t-1} + q_{i,t} - ET_{i,t} - T_{i,t} - \sum_{j=1}^{3} D_{i,j,t} - SP_{i,t} \qquad (8)$$

- For recipient reservoir:

$$S_{i,t} = S_{i,t-1} + q_{i,t} - ET_{i,t} + T_{i,t} - \sum_{j=1}^{3} D_{i,j,t} - SP_{i,t} \qquad (9)$$

Where, $S_{i,t-1}$ and $S_{i,t}$ is the storage of reservoir i at the beginning and end of period t (Mm^3); $q_{i,t}$, $ET_{i,t}$ and $T_{i,t}$ are the inflow, evaporation loss and water transferred that occurs during period t ; $D_{i,j,t}$ is the water consumptions of different users for reservoir i in the period t.

IV. Conclution

With an arid to semi-arid climate, water resources in Morocco are very limited. Thus, the variability of rainfall and inflows between the north and the south increases the scarcity appearances; hence the use of projects such as the transfer of surplus water from the north to deficit areas in the south seems reasonable. Managing multi-reservoir system, characterized by high dimensional problems and multiple constraints, is very complex. However, use of optimization methods helps to obtain satisfactory results.

Particle Swarm Optimization (PSO), as a stochastic Evolutionary Algorithm (EA), has powerful advantages for the efficiency and accuracy of optimal operations for large-scale multi-reservoirs. Nonetheless, PSO becomes incapable when confronting with the high-dimensional, multi-constrained combinatorial problems, because of the complicatedly association within variables and its premature convergence property. That's why many authors have developed novel methods to improve the PSO performances as mentioned above. Progressive Reservoir Algorithm Particle Swarm Optimization (PRA-PSO), tested successfully by Wan et al., would be adopted in this study. PRA-PSO could be also linked to Water Evaluation and Planning System (WEAP), as simulation model, in order to approximate the behavior of the system studied and test different scenarios. This operation, tested recently by some authors, has shown good results.

References

[1] Kummu M., Ward P.J., H. de Moel and Varis O., (2010). Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. Environ Res Lett, 5 (2010), p. 034006. DOI:10.1088/1748-9326/5/3/034006.

[2] Dahal V., Shakya N. M., Bhattarai R., (2016). Estimating the impact of climate change on water availability in Bagmati Basin, Nepal. Environ Process 3:1–17.

[3] Abdulbaki D., Al-Hindi M., Yassine A., Abou Najm M., (2017). An optimization model for the allocation of water resources. Journal of Cleaner Production 164 (2017) 994e1006.

[4] Anzab N. R., Mousavi S. J., Rousta B. A. and Kim J. H., (2016). Simulation Optimization for Optimal Sizing of Water Transfer Systems. p 365-376. DOI: 10.1007/978-3-662-47926-1_35.

[5] Hınçal O., Sakarya A., and Ger A., M., (2011). Optimization of Multireservoir Systems by Genetic Algorithm. Water Resour Manage, 25:1465–1487. DOI 10.1007/s11269-010-9755-0.

[6] Gu W., Shao D., Tan X., Shu C. and Wu Z., (2017). Simulation and Optimization of Multi-Reservoir Operation in Inter-Basin Water Transfer System. Water Resour Manage. DOI 10.1007/s11269-017-1675-9.

[7] Ghassemi F. and Ian White I., (2007). Inter-Basin Water Transfer: Case Studies from Australia, United States, Canada, China and India (International Hydrology Series). Australian National University.

[8] Gupta P and Zaag V., (2008). Interbasin water transfers and integrated water resources management: Where engineering, science and politics interlock. Physics and Chemistry of the Earth 33 (2008) 28–40.

[9] Zhu X., Zhang C., Yin J. et al., (2014). Optimization of water diversion based on reservoir operating rules: analysis of the Biliu River reservoir, China. J Hydrol Eng 19(2):411–421.

[10] Minard A. (2015). Inter-basin Water Transfers. Water Matters! pp. 19-1 – 19-10. http://uttoncenter.unm.edu/pdfs/water-matters-2015/19_Inter-basin_Water_Transfers.pdf.

[11] Zhuang, W., (2016). Eco-environmental impact of inter-basin water transfer projects: a review. Environ Sci Pollut Res, 23:12867–12879. DOI 10.1007/s11356-016-6854-3.

[12] Wan W., Guo X., Lei X., Jiang Y., Wang H., (2017). A Novel Optimization Method for Multi-Reservoir Operation Policy Derivation in Complex Inter-Basin Water Transfer System. Water Resour Manage. DOI 10.1007/s11269-017-1735-1.

[13] Oliveira R. and Loucks D. P., (1997). Operating rules for multireservoir systems. Water Resources Research, VOL. 33, N°. 4, pages 839-852.

[14] Lin M. N. and Rutten M., (2016). Optimal Operation of a Network of Multi-Purpose Reservoir: A Review. 12th International Conference on Hydro-informatics, HIC.

[15] Wei C. C, Hsu N. S., (2008). Derived operating rules for a reservoir operation system: comparison of decision trees, neural decision trees and fuzzy decision trees. Water Resour Res 44: W02428.

[16] Soleimani S, Bozorg-Haddad O, Loaiciga H., (2016). Reservoir operation rules with uncertainties in reservoir inflow and agricultural demand derived with stochastic dynamic programming. J Irrig Drain Eng 142(11): 04016046.

[17] El Harraki W., Driss O., Bouziane A. and Hasnaoui M. D., (2016). Genetic Algorithm applied to reservoir operation optimization with emphasis on the Moroccan context. Hydraulic Systems Analysis Laboratory. Mohammadia School of Engineers-EMI-Rabat, Morocco.

[18] Loucks DP, Van Beek E, Stedinger JR, Dijkman JP, Villars MT. (2005). Water resources systems planning and management: an introduction to methods, models and applications: Paris: UNESCO.

[19] Jetmarova H., M., Sultanova N., Savic D., (2017). Lost in optimization of water distribution systems? A literature review of system operation. Environmental Modelling & Software 93 (2017) 209e254.

[20] Wang Y., Shi H. S., Wang J. and Zhang Y., (2015). Research and application of water resources optimized distribution model in Inter-Basin Water Transfer project. In: Applied Mechanics and Materials. Trans. Tech. Publ., vol. 737, pp. 683–687.

[21] Jain SK, Reddy NSRK, Chaube UC (2005) Analysis of a large inter-basin water transfer system in India. Hydrol Sci J 50(1) :125–137.

[22] Sadegh M, Mahjouri N, Kerachian R (2010) Optimal inter-basin water allocation using crisp and fuzzy shapley games. Water Resour Manag 24(10): 2291–2310.

[23] Salim S., B., (2013). Stochastic optimization of water transfer between dams. 2nd World Conference On Business, Economics and Management (WCBEM).

[24] Rani D, Srivastava DK, Gulati TR (2016) A set of linked optimization models for an inter-basin water transfer. Hydrol Sci J 61(2) :371–392.

[25] Yeh W. W. G., (1985). Reservoir management and operations models: A state-of-the-art review," Water Resources Research, vol. 21, no. 12, pp. 1797-1818.

[26] Stuckman B., E., (1988). A Global Search Method for Optimizing Nonlinear Systems. IEEE. Transactions on Systems, Vol. 18. N°6.

[27] Needham J. T., Jr D. W., Lund J. R. and Nanda S. K., (2000). Linear programming for flood control in the Iowa and Des Moines Rivers. Water Resources Planning and Management, vol. 126, no. June, pp. 118-127.

[28] Li X., Wei J., Tiejian, Wang G. and Yeh W. W. G., (2014). A parallel dynamic programming algorithm for multir-reservoir system optimization. Advances in Water Resources, vol. 67, pp. 1-15.

[29] Pricea E., and Ostfelda A. (2014). Battle of Background Leakage Assessment for Water Networks Using Successive Linear Programing. 16th Conference on Water Distribution System Analysis, WDSA 2014.

[30] Belsnes MM, Wolfgang O, Follestad T, Aasgård EK. (2016). Applying successive linear programming for stochastic short-term hydropower optimization. Electr Power Syst Res 130:167–180.

[31] Xua Y., Wangb Y., Lia S., Huangc G., Dai C. (2017). Stochastic optimization model for water allocation on a watershed scale considering wetland's ecological water requirement. Ecological Indicators.

[32] Xie Y.L., Xiaa D.X., Jib L. and Huangc G.H. (2017). An inexact stochastic-fuzzy optimization model for agricultural water allocation and land resources utilization management under considering effective rainfall. Ecological Indicators, doi: 10.1016/j.ecolind.2017.09.026.

[33] Cheng C, Shen J, Wu X, Chau K. (2012). Short-term Hydro-scheduling with discrepant objectives using multi-step progressive optimality Algorithm1. JAWRA J Am Water Resour Assoc 48(3):464–479. Doi.org/10.1111/j.1752-1688.2011.00628.x.

[34] Peng Y., Chu J., Peng A and Zhou H. (2015). Optimization-Operation Model Coupled with Improving Water-Transfer Rules and Hedging Rules for Inter-Basin Water Transfer-Supply Systems. Water Resour Manage. DOI 10.1007/s11269-015-1029-4.

[35] Feng Z., Niu W., Cheng C. and Wuc X. (2017). Peak operation of hydropower system with parallel technique and progressive optimality algorithm. Electrical Power and Energy Systems 94 (2018) 267–275.

[36] Ashofteh P, Haddad OB and Loáiciga HA. (2015). Evaluation of climatic-change impacts on multi-objective reservoir operation with multi-objective genetic programming. J Water Resour Plan Manag. 141(11):4015030.

[37] Behnam Vahdani B., Niaki S.T.A. and Aslanzade S. (2017). Production-Inventory-Routing Coordination with Capacity and Time Window Constraints for Perishable Products: Heuristic and Meta-heuristic Algorithms. PII: S0959-6526(17)31053-3. JCLP 9652. Journal of Cleaner Production. DOI: 10.1016/j.jclepro.2017.05.113.

[38] Marin A., and Pelegrin M. (2017). Towards unambiguous map labeling - Integer Programming approach and heuristic algorithm. PII: S0957-4174(17)30764-9. ESWA 11657. DOI: 10.1016/j.eswa.2017.11.014.

[39] Kennedy J. and Eberhart R., (1995). Particle swarm optimization. In: Proceedings of 2004 International Conference on Machine Learning and Cybernetics, pp. 1942–1948. IEEE Press.

[40] Engelbrecht, A. P. (2007). Computational intelligence: An introduction (2nd ed.). John Wiley and Sons.

[41] Parsopoulos, K.E., Plagianakos, V.P., Magoulas, G.D., Vrahatis, M.N. (2001). Stretching technique for obtaining global minimizers through particle swarm optimization. In: Proceedings of the Particle Swarm Optimization Workshop, Indianapolis, USA.

[42] Xu G. and Yu G. (2017). On convergence analysis of particle swarm optimization algorithm. Journal of Computational and Applied Mathematics. CAM 11356. PII: S0377-0427(17)30527-7. doi.org/10.1016/j.cam.2017.10.026.

[43] Martins, M. S. R., Fuchs S.C., Pando L.U., et al. (2013). PSO with path relinking for resource allocation using simulation optimization. Computers & Industrial Engineering, doi:10.1016/j.cie.2013.02.004.

[44] Ho S. L., Yang S., Ni G., and Wong H. C. (2006). A Particle Swarm Optimization Method with Enhanced Global Search Ability for Design Optimizations of Electromagnetic Devices. IEEE. Transactions on Magnetics, Vol. 42, N° 4, p1107-1111.

[45] Ye W., Feng W. and Fan S. (2017). A novel multi-swarm particle swarm optimization with dynamic learning strategy. Applied Soft Computing 61 (2017) 832–843.

[46] Chen Y., Li L., Peng H., Xiao J., (2017a). Dynamic multi-swarm differential learning particle swarm optimizer. Swarm and Evolutionary Computation BASE DATA. PII: S2210-6502(16)30538-7. SWEVO 319. DOI: 10.1016/j.swevo.2017.10.004.

[47] Lynn N., Ali M.Z. and Suganthan P. N. (2017a). Population topologies for particle swarm optimization and differential evolution, Swarm and Evolutionary Computation Base Data doi: 10.1016/j.swevo.2017.11.002.

[48] Machado-Coelho T.M., Machado L. (2017). An Interval Space Reducing Method for Constrained Problems with Particle Swarm Optimization. Applied Soft Computing. ASOC 4226. DOI: http://dx.doi.org/doi:10.1016/j.asoc.2017.05.022.

[49] Chen Y., Li L., Peng H., Xiao J. (2017b). Particle Swarm Optimizer with two differential mutations. Applied Soft Computing. PII: S1568-4946(17)30431-3. ASOC 4348. DOI: 10.1016/j.asoc.2017.07.020.

[50] Kiran M. S. (2017). Particle Swarm Optimization with a New Update Mechanism. Applied Soft Computing. DOI: 10.1016/j.asoc.2017.07.050.

[51] Marinaki M, Marinakis Y, Stavroulakis GE. (2011). Vibration control of beams with piezoelectric sensors and actuators using particle swarm optimization. Expert Syst Appl 38(6):6872–6883.

[52] Triguerosa D. E. G., Modenesb A. N., (2012). Reuse water network synthesis by modified PSO approach. Chemical Engineering Journal 183 (2012) 198– 211.

[53] Abdelaziz R. and Zambrano-Bigiarini M. (2014). Particle swarm optimization for inverse modeling of solute transport in fractured gneiss aquifer. J Contam Hydrol 164(0):285–298. Doi.org/10.1016/j.jconhyd.2014.06.003.

[54] Afshar A and Masoumi F. (2016) Waste load reallocation in river–reservoir systems: simulation–optimization approach. Environ Earth Sci 75(1): p1–14.

[55] Jiang Y., Liu C., Huang C., Wu X. (2010). Improved particle swarm algorithm for hydrological parameter optimization. Appl Math Comput 217(7):3207–3215.

[56] Ostadrahimi L., Mariño M.A., Afshar A. (2012). Multi-reservoir operation rules: multi-swarm PSO-based optimization approach. Water Resour Manag 26(2):407–427.

[57] Wang Q., Zhou H., Liang G. and Xu H. (2015). Optimal Operation of Bidirectional Inter-Basin Water Transfer-Supply System. Water Resour Manage (2015) 29 :3037–3054. DOI 10.1007/s11269-014-0905-7.

[58] Shourian M., Mousavi S. J. and Tahershamsi A. (2007). Basin-wide Water Resources Planning by Integrating PSO Algorithm and MODSIM. Water Resour Manage (2008) 22:1347–1366. DOI 10.1007/s11269-007-9229-1.

[59] Guo X., Hua T., Tao Zhang T. and Lv Y. (2012). Bi-level model for multi-reservoir operating policy in inter-basin water transfer-supply project. Journal of Hydrology. 424–425, p 252–263. DOI: 10.1016/j.jhydrol.2012.01.006.

[60] Zeng X., Hu T., Guo X. and Li X. (2014). Water Transfer Triggering Mechanism for Multi-Reservoir Operation in Inter-Basin Water Transfer-Supply Project. Water Resour Manage. DOI 10.1007/s11269-014-0541-2.

[61] Peng Y., Zhang X., et al., (2016). Multi-Core Parallel Particle Swarm Optimization for the Operation of Inter-Basin Water Transfer-Supply Systems. Water Resour Manage. DOI 10.1007/s11269-016-1506-4.

[62] Wan F., Yuan W. and Zhou J. (2016). Derivation of Tri-level Programming Model for Multi-Reservoir Optimal Operation in Inter-Basin Transfer-Diversion-Supply Project. Water Resour Manage. DOI 10.1007/s11269-016-1540-2.

[63] Mousavi S. J., Anzab N. R., Asl-Rousta B. and Kim J. H. (2017). Multi-Objective Optimization-Simulation for Reliability-Based Inter-Basin Water Allocation. Water Resour Manage. DOI 10.1007/s11269-017-1678-6.

[64] Guo X., Hu T., Wu C. et al., (2013). Multi-Objective Optimization of the Proposed Multi-Reservoir Operating Policy Using Improved NSPSO. Water Resour Manage (2013) 27:2137–2153. DOI 10.1007/s11269-013-0280-9.

[65] Direction des Aménagements Hydrauliques (DAH), (2017). Etude de conception du projet d'utilisation des eaux excédentaires des bassins du nord. Secrétariat d'Etat chargé de l'Eau - Maroc.