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Optimum socio-environmental flows approach for reservoir operation strategy using many-objectives evolutionary optimization algorithm

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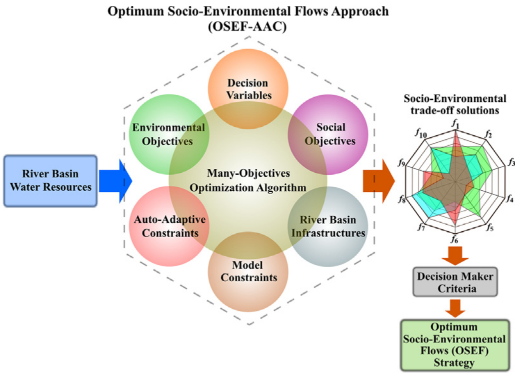
HIGHLIGHTS

- Decision makers rarely considered environmental flows regime in their strategy
- Novel optimum socio-environmental flows (OSEF-AAC) approach was developed
- The approach evaluated by a case study using nine objectives with two optimizers
- The robustness of OSEF-AAC is endorsed by improving river basin environments and revenues

GRAPHICAL ABSTRACT



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ABSTRACT

Water resource system complexity, high-dimension modelling difficulty and computational efficiency challenges often limit decision makers' strategies to combine environmental flow objectives (e.g. water quality, ecosystem) with social flow objectives (e.g. hydropower, water supply and agriculture). Hence, a novel Optimum Social-Environmental Flows (OSEF) with Auto-Adaptive Constraints (AAC) approach introduced as a river basin management decision support tool. The OSEF-AAC approach integrates Socio-Environmental (SE) objectives with convergence booster support to soften any computational challenges. Nine SE objectives and 396 decision variables modelled for Iraq's Diyala river basin. The approach's effectiveness evaluated using two non-environmental models and two inflows' scenarios. The advantage of OSEF-AAC approved, and other decision support alternatives highlighted that could enhance river basin SE sectors' revenues, as river basin economic benefits will improve as well. However, advanced land use and water exploitation policy would need adoption to secure the basin's SE sectors.

1. Introduction

The limits of water resources often lead to building dams in arid-environments to fulfil social and environmental demands such as flood wave absorption, water supply, agriculture projects, producing hydropower, tourist attraction, and other recreational purposes. These structures and their catchments need a robust management plan to

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handle their complexity in terms of: non-linearity, dynamic characteristics, conflicting objectives, multimodal, etc. (Haimes and Hall, 1977 in Reed et al., 2013).

In the last few decades optimization algorithms developed and carried out in different scientific and engineering fields to solve complex problems (Coello et al., 2007); these problems include water resources management (Maier et al., 2014). Multiple optimization methods used in reservoir system operation including linear and non-linear programing, dynamic programing and evolutionary algorithms (Ahmad et al., 2014; Rani and Moreira, 2010). Evolutionary algorithms (EA) widely employed to tackle the intricacies of reservoir systems, inspired from evolution of genes (Nicklow et al., 2010; Back et al., 2000). Studies involving multi-objective reservoir operation optimization using evolutionary algorithm summarized in Table 1. Only three of the twenty-two studies consider more than five objectives in reservoir operation strategy (multiple publications used in the same case study considered as one study). Besides, some studies merge objectives to simplify the multiple dam system problems, and hydropower generation and water supply (for domestic and irrigation) were the dominant objectives adopted in these studies.

Environmental objectives seldom adopted in reservoir management, in a recent review of studies between 1980 and 2015 by Horne et al. (2016) found only 42 studies adopt environmental releases in reservoir management as decision variables.

Recently Horne et al. (2017) presented conditional probability networks (CPNs) approaches combined with Mixed Integer Programing (MIP) optimizer for environmental flow regimes. Poff et al. (2016) propose a framework approach for eco-engineering decision scaling using performance indices, and Acreman et al. (2014) show that environmental flows need a “designer” approach for considering ecosystem objectives in water control infrastructure, rather than a “natural” approach.

Older studies do consider social objectives (hydropower, water supply, and flood protection) in their optimization models for reservoir operation strategy, and more recent studies consider environmental flow regimes. We propose to adopt a more holistic approach, where environmental flows from reservoir combined with the social water needs to improve economic revenues reliant on the river basin system.

Water resources management models provide information to the decision makers, rather than the decision itself (Loucks, 2012). There are pre and post-optimization implementation approaches for incorporating decision maker criteria within a multi-aspects problems (Maier et al., 2014; Coello et al., 2007). One of the pre-criteria approach drawbacks is the dissatisfaction (or lack of trust) of decision makers towards model results that emerged depending on their criteria set, and they may change these criteria to produce new results (Loucks, 2012). Hence the model needs to be re-executed until they get satisfaction. The second approach is computationally challenging and has potential difficulties to find the Pareto-front for optimum solutions set, which recently tackles by using multi-objective (or many-objective for more than three objectives) optimization algorithms (Maier et al., 2014).

These holistic challenges motivate development of a novel approach to produce optimum river basin management strategies that combines both social and environmental objectives. Many-objective evolutionary optimization algorithm adopted to conceptualize and analyse the multi-sector problem. Also, an auto-adaptive constraints approach used to overcome system complexity and boost algorithm convergence. The approach effectiveness evaluated using challenging water resources problem in a semi-arid region in Middle East. The approach achievement and robustness supported by two evolutionary algorithms (Maier et al., 2014): the state-of-the-art Borg MOEA (Hadka and Reed, 2013) and the new ε-DSEA (Al-Jawad et al., 2018b). The findings expected to improve the river basin system potential social and environmental sectors economic revenues. Also, the optimum water management strategy “trade-off” will provide the decision makers with a flexible flow regime management consistent with different time-scales for real-world IWRM.

2. Methods and tools

2.1. Identification of OSEF-AAC approach

This study presents the Optimum Socio-Environmental Flows (OSEF) approach which combines all social and environmental sectors (or objectives) together in one model using a many-objectives optimization algorithm approach.

Table 1
Summary of literatures used evolutionary algorithms to optimize multi-objective reservoir operation strategy.

Author	Method	Objective no.	Subject	No. of dams
Kim et al. (2008)	NSGA-II	2	Water shortage index + hydropower	1
Chang and Chang (2009)	NSGA-II	2	Water shortage index for two dams	2
Dittmann et al. (2009)	MOES	5	Inundation + overtopping for three dams + releases	3
Reddy and Kumar (2009)	MOPSO	2	Hydropower + irrigation	1
Regulwar (2009)	MOGA	2	Hydropower + irrigation	5
Hakimi-Asiabar et al. (2010)	SLGA	3	Hydropower + water supply + water quality	3
Wang et al. (2011)	MIGA	2	Long term operation for water demand and storage	1
Malekmohammadi et al. (2011)	NSGA-II	2	Flood + water demands	2
Schardong et al. (2013)	MODE	3	Water demands + water quality + pumping cost	5
Kasprzyk et al. (2013)	ε-NSGA-II	6	Two cost + Three reliability + Market use	1
Giacomoni et al. (2013), Giuliani et al. (2014a)	Fitted Q-iteration	5	Two Recreation + sedimentation + water deficit + Temperature differences	1
Giuliani et al. (2014b), Giuliani et al. (2016), Salazar et al. (2016, 2017)	Borg MOEA	6	Three water supply + hydropower + recreation + environment	1
Ahmadianfar et al. (2015)	MOEA/D	2	Flow demands + agriculture demands	3
Li and Qiu (2015)	NSGA-II	2	Hydropower + firm power	1
Amirkhani et al. (2016)	NSGA-II	2	Water quality + water temperature	1
Hurford et al. (2014)	ε-NSGA-II	10	Four agriculture water deficit + water losses + Hydropower + Land availability + Two Flow alteration	3
Qi et al. (2016)	MOEA/D	2	Water level + releases	1
Chen et al. (2016)	NSGA-II	5	Water supply + hydropower + flow alternation in two rivers + water quality	1
Dai et al. (2017)	NSGA-II	2	Hydropower + water alternation	2
Alrajoula et al. (2016)	PSO	1	Water allocation cost	1
Uen et al. (2018)	NSGA-II	2	Hydropower + storage	1
Li et al. (2017)	GP	2	Hydropower + water resources fee	1