Multi-criteria decision making methods to address water allocation problems: A systematic review

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Supplementary material (Table S1)

49 published papers between 2000-2019 and indexed by four literature databases (Web of Science, Science Direct, Scopus, and Google scholar) were reviewed. The application of MCDM methods to solve water allocation problems under different water-problem based classification (water shortage, water use management, water quality, ecosystem/environment management, flood management, combined water problems) is presented in table format. It contains the summary of each reviewed paper (problem gap motivated, objectives, criteria, decision techniques used).

Table S1: An overview on the reviewed literature (problem gap, objective, criteria, and decision-making technique)

Water shortage based problem					
Author	**Problem/ motivation**	**Objectives**	**Criteria/indicator**	**MCDM**	**Decision-Making Techniques**
[1]	water shortage (water supply-demand mismatch)	maximize the total economic benefit of the entire area	optimal quotas for (community, ecological, and economic use); population, territorial area;	MODM	dynamic model
[2]	declining in the availability of groundwater reservoirs (issue of sustainability)	maximizing recharge, maximizing biodiversity, maximizing short term economic gains, maximizing food security, maintaining zero abstraction for public water supply	quantitative indicators (environment (climate, land uses, land management, water allocations), river gauge or river reach), economic and social (policies))	MODM	Model (DSS)Innovative modeling approaches
[3]	water planning problem (incisive supply-demand contradiction, ecosystem deterioration)	maximization of total net return from water supply system	water-availability, water-demand in the sectors, water demand by ecosystem, water-security	MODM	IQP
[4]	allocation of water problem among competing uses	maximize the net present value of water from allocating it between competing uses	drought status, the current weather, weather correlation, and current storage, controls (environmental release and irrigation allocation)	MODM	dynamic programming
[5]	water allocation complexity problem among stakeholders	maximize water resources supply profits of each riparian stakeholder	water balance, environmental demand, and usage	MODM	MIP
[6]	imbalance water uses by human and ecosystems	minimization of water index; maximization of habitat index	water and habitat indices	MODM	weighted sum method
[7]	water supply shortage for agriculture and industry	minimize industry and agriculture water shortages	storage volumes, time step, agricultural water supply, industrial water supply	MODM	NSGAII
[8]	reservoir water allocation problem	minimizing unmet demands, minimizing the deviation to the full storage, minimizing the water productivity losses function, minimize	hydraulic (storage bound in the surface water sources, flow capacities of transmission links from sources to demand sites in any time period) and storage continuity requirements	MODM	GA (OPTIWAM: Optimizing Irrigation Water Management)

		reservoir infiltration and deep percolation and water withdrawal from the aquifers, minimizing the unit cost of water over the management area throughout the study period			
[9]	water shortage problem (unmet demands)	maximizes the total net profits of users	supply, demand, environmental water requirement	MODM	MIP
[10]	water allocation shortage problem	economic objective (minimize cost); transfer objectives (minimize water deficit); environmental objectives (maximizing environmental benefits)	output quantity of the water for each region is less than 20%; water must meet the demand. relative water volume between transfer rivers,	MODM	GA
[11]	limited water resources	maximize agricultural system benefits	irrigation benefit, economic penalty, water available and irrigation quota	MODM	interactive two-stage fuzzy stochastic programming (ITFSP)
[12]	severe water shortages in the region	minimize water abandonment, maximize available water quantity	(1);although the cost of sewage treatment is high, the sewage must be treated and used preferentially to protect the environment; (2) diversion water should be used in preference to local water; (3) underground water is divided into three portions for use	MODM	rule-based
[13]	water shortage	minimize the water shortage for the whole watershed and balance the water shortage in different districts	economic (output, profits, gross national product, and gross living product);social (social stability, quality of life, employment and education); environment (minimizing water quality loss caused by water pollution, maximizing water environment benefits, maintaining the ecosystem balance and improving the ecological system)	MODM	GA
[14]	water shortage or scarcity	maximizing domestic water use equality, maximizing agricultural water use equality. minimizing industrial water use benefits equality	water availability, ecological water requirements, water demand	MODM	GA, compromise programming
[15]	limited water availability (unmet demands)	minimizing industry water shortage, minimizing agriculture water shortage, minimizing water spillage, maximizing ecological satisfaction, minimize the	initial water storage at the beginning of period t, ending water storage at the end of period t, inflow, water imported, water supply, water spillage, evaporation loss,	MODM	ε-NSGA II

		amount of water transfer	maximum storage, minimum storage, and maximum water transfer capacity in period t,		
[16]	water scarcity and poor management	evaluating water resource management strategies	water balance, net profit, and full cost of water	MADM	MAUT,AHP, ELECTRE,TOPSIS
[17]	long periods of water shortages	to balance water supply-demand strategies	implementation cost(min),response time(min),social benefit (max),demand reduction(max),viability(min),water supply(max)	MADM and MODM	PROMETHEE V(out ranking),ILP
[18]	severe water shortage	enhancing water-use efficiency, development of alternative water sources and improvement in effective water management	technical (water-supply potential, systemic energy efficiency),economic (economic feasibility);environmental (climate-related stability)	MADM	weight
[19]	water shortage_ demand allocation	maximize hydropower output (generation),maximize water supply reliability	reservoir water storage, water demand, reservoir water inflow	MODM	(NSGA-II)
Water use management based problem					
Author	**Problem/ motivation**	**Objectives**	**Criteria/indicator**	**MCDM**	**Decision Making Techniques**
[20]	water resources planning policies problem	minimize(evaporative/spill loss; hydropower deficit; fisheries deficit; agricultural deficit, flow alteration);maximize (land availability)	evaporation rate, hydropower production, agriculture production, fish production, land area, water flow	MODM	epsilon Dominance Non-dominated Sorted Genetic Algorithm-II (e-NSGAII)
[21]	water resource management problem	supply-demand equilibrium, drought mitigation, and economic efficiency	domestic water supply, industrial water supply, agricultural water supply, environmental water supply; benefit-cost ratio, net benefit, economic risk; maximum drought duration and severity, drought loss	MODM	TOPSIS
[22]	water use efficiency problem	maximum economic benefit and minimize water shortage	surface water supply, groundwater supply, minimum water requirement level, maximum water requirement level	MODM	fuzzy programming; (TLFWM(two-level linear fractional water management)) and stochastic two-level linear fractional chance-constrained water management

					(STLFCWM)
[23]	need for culture-based fisheries (CBFs), a form of extensive aquaculture	to select a suitable reservoir (non-perennial reservoirs) for culture-based fisheries	reservoir productivity, catchment characteristics, and socio-economic factors	MADM	AHP
[24]	technical water allocation problem	to assess the harmoniousness of water resources allocation	diversity of water authorities, autonomy of water users, data accessibility and sharing, GDP output per unit water, ratio of industrial water to agricultural water, utilization rate in canal system, wastewater recycling rate, water resources per capita, water amount per unit area, percentage of forest cover, integrated water qualification rate, sewage treatment rate, percentage of ecological water utilization, urbanization rate, per capita GDP	MODM	CCM (compound cloud model)
[25]	water demand for power generation and ecological benefits balance problem	maximize power generation and minimize ecological flow shortage	reservoir storage, reservoir water level, turbine release, power output, release outflow, penality	MODM	NSGA-II
[26]	water stresses and food scarcity	minimization of (power deficit, maintenance of water availability for irrigation to support food self-sufficiency, reduction in flood risk, maintenance of environmental flows), and maximization of power export	water availability, Irrigation demand fulfillment, environmental flow fulfillment, storage continuity, end storage, storage target fulfillment, turbine flow, turbine capacity, release capacity, storage capacity, production capacity, power supply, power deficit,	MODM	LP
[27]	water management problems	maximize net revenue, minimize variable costs, minimize groundwater pumping	available water, cultivated area, environmental flow, groundwater pumping, cropping areas	MODM	(NSGA-II)
[28]	water management or reservoir operation management problem	minimization of deviation to develop an optimal reservoir operational programming (to calculate ecological water demands under steady and pulse states; construction of the proposed IMOOM considering ecological water demands under multiple hydrologic runoff guarantee rates, setting the	discharge flow quantity, canal flow volume, diversion pipe flow, economic benefits of Danjiangkou and the Taocha Canal headwork, flood control, water supply, power generation, ecological water demand	MODM	GP

		maximum of core ecosystem service function values as the operational target			
[29]	prioritization of tradeoffs inwater allocation problem	to prioritize water allocation options that trade-off socio-economic and hydro-ecological benefits in rivers without direct interaction with decision-makers (i.e. tradeoffs prioritizing tradeoffs that favored either irrigation or hydro-ecological condition)	water extracted for irrigation, net benefits to irrigation, average spring terrestrial vegetation encroachment into the river channel, maximum spring terrestrial vegetation encroachment into river channel, water allocation to suppress terrestrial vegetation encroachment	MODM	NSGA-II,CP
[30]	water allocation problem	minimize variation between required minimum flow and discharge, maximize hydropower potential of the key reservoirs, minimize the average number of days that discharge is less than the required minimum flows	to keep the storage of the six key reservoirs between their dead storage and capacity	MODM	eNSGAII,NSGAII, OMOPSO, MOEAs, GDE,SPEA,SMPSO
[31]	sustainable water resource management problem	maximize net benefits by optimize water allocation schemes over the planning horizon	water availability, water demand by vegetation, Water demand by sectors, target water delivery,penalities,	MODM	(MFSP)multi-stage fuzzy stochastic programming
Water quality-based problems					
Author	**Problem/ motivation**	**Objectives**	**Criteria/indicator**	**MCDM**	**Decision Making Techniques**
[32]	saltwater intrusion into aquifer	maximization of the extracted volume of freshwater from the aquifer, maximization of the contaminant mass removal; minimization of the total cost of a remediation system	penalty and hydraulic head threshold	MODM	LP and heuristic optimization (differential evolution,DE)
[33]	water pollution problem	application of use-based water quality ladders in the valuation of environmental benefits in the context of the Water Framework Directives(WFD)	Zone, Water quality use, Water bill increase	MADM	AHP
[34]	integrated wastewater management system problem	minimization of the CSO volume(combined sewer overflows);minimization of ecological impacts, and minimization of volume discharged, and also minimization of	discharged hydraulic load, amount of ammonia, nitrate concentration, energy or total operation costs	MODM	Fuzzy programming

		cost			
[35]	marine pollution problem in coastal zones	suitable site selection of industrial wastewater discharge in coastal regions	consistency with marine function zone and marine law, marine dilution conditions, ecological risk, engineering risk and project cost, engineering cost	MADM	AHP
[36]	poor quality of water problem	minimize allocation of monitoring sites, maximized detection of pollutant areas, maximize population protection benefit areas, maximize river hydrological category benefits	cost, number of stations, budget	MODM	Multi-Objective Artificial Bee Colony-based optimization approach (MOABC)
[37]	groundwater contamination problem	minimize cost, sum of contaminant concentrations that violate standard and contaminant plume fragmentation	contaminant concentration at all nodes of the study area should not violate the standard at the end of the bioremediation period, hydraulic head lower and upper bound, injection and extraction flow rates should be less than the well injection or extraction capacity	MODM	NSGA-II
[38]	water-quality problem (phosphorous export to downstream areas)	maximizing hydropower energy production from a network of reservoirs, minimizing the total phosphorous discharge	water remaining in the reservoirs, reservoir level and discharge	MODM	NSGA-II
[39]	water resources allocation strategies and emission control problem	maximize total system benefit in the river basin (Water utilization benefits, water shortage penalty, water supply cost, wastewater treatment cost, environmental capacity improvement cost)	water supply, demand of water use sectors, regional wastewater treatment capacity, regional wastewater reuse capacity, total emissions of water pollutants, water environment carrying capacity, engineering for carrying capacity improvement	MODM	ITSP (inexact two-stage stochastic programming model)
Water environmental/ecosystem-based problems					
Author	**Problem/ motivation**	**Objectives**	**Criteria/indicator**	**MCDM**	**Decision Making Techniques**
[40]	wetland ecosystem protection problem	maximize ecological or ecosystem health; maximize economic returns	water volume; water use; water balance between water release and the water level; water level	MODM	GA,Fuzzy
[41]	decline in fish habitat protection(ecosystem disturbance)	maximizing river habitat suitability for fish survival, maximizing the hydropower production	minimum flow requirement level, habitat conditions of the river stretch, energy production needs	MODM	NSGA II, e-constraint methods

[42]	economic and environmental benefits balance problem	minimizes the impact on the environment, maximizes the utility function of income	land availability, forest area, soil property, minimum agricultural area size, minimum residential area size, land slope, minimum recreational area size, minimum water-body area, total phosphorous assimilative capacity	MODM	multi-objective game-theory model(MOGM),e constraint
[43]	environmental concerns (high salinity load increment)	maximize the outflow; minimize salinity load, maximize water allocations to the agricultural fields	water demand of the agricultural water user, streamflow downstream of the withdrawal point of agricultural water user, minimum environmental flow	MODM	GA; surrogate worth trade-off (SWT) method
[44]	environment problems	maximizing the comprehensive benefits (environmental, ecological, social and economic)	minimum ecological flow, maintain minimum water quality standards, flood control,	MODM	(FS-DDDP)Feasible search discrete differential dynamic programming
Flood based problems					
Author	**Problem/ motivation**	**Objectives**	**Criteria/indicator**	**MCDM**	**Decision Making Techniques**
[45]	decision-making problem of flood operation in a multi-reservoir system	minimizing the maximum flood release value from a reservoir and minimizing the maximum water level in the upstream reservoir; maximizing hydropower generation and maximizing flood control benefits; minimizing peak flow at a downstream flood control point and minimizing maximum water level in the upstream reservoir	Outflow limitation, water level limitation, water continuity in reservoir, water continuity amid reservoirs, start and end water level	MODM	multi-objective best compromise decision model (MoBCDM),FAHP, segmentation and averaging (Seg/Ave),differential evolution (DE) algorithm
Combined water problems					
Water shortage and water quality based problems					
Author	**Problem/ motivation**	**Objectives**	**Criteria/indicator**	**MCDM**	**Decision Making Techniques**
[46]	limited water quantity and quality	prioritization of water management strategies	cost; driving force(population and population density), impact (urban area ratio, groundwater withdrawal, slope of watershed ,ratio of covered stream length, state and pressure (DPSIR framework (Driving force-Pressure-State-Impact Response))	MADM	ELECTRE II, AVF (simple additive weighting method)

[47]	water supply limitation and water pollution problem	maximize economic growth, water utilization, and water environment benefits	water quantity, water quality, water pollutants, water supply-demand balance, water environmental carrying capacity	MODM	LP
[48]	water quantity and quality management problem	allocating wastewater and urban runoff to agricultural lands and groundwater recharge	groundwater controlling, cost, environmental water right, keeping surface and groundwater quality, water supply	MADM	Fuzzy(modified fuzzy social choice (MFSC)
Water shortage and flood based problems					
Author	**Problem/ motivation**	**Objectives**	**Criteria/indicator**	**MCDM**	**Decision Making Techniques**
[49]	water is insufficient; water availability is variable in space and time, spatiotemporal discrepancy in demand	minimize all costs caused by unmet demands as well as by floods in river segments; to optimally meet water demands,	regulate mass balance water flow between locations; capacity (reservoir and river segment);continuity	MODM	LP

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