A Comprehensive Evaluation: Water Cycle Algorithm and Its Applications

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Abstract. Recently nature-inspired optimization algorithms have become a popular choice for solving complex optimization problems. Water Cycle Algorithm (WCA) is a nature-inspired new optimization technique, which has successfully applied to solve the constrained optimization and engineering design problems. As a result, the WCA studies have extended significantly in the last 5 years. This review paper provides the comprehensive assessment of WCA in the area of modifications, hybridizations, and applications. Moreover, it will provide the awareness to the researchers how the current algorithm can be modified according to the nature of the problems. The narrative of how WCA was used in the tactics for solving these kinds of problems. Future research directions are also discussed based on the comprehensive conclusion as well as discussion. To the best of our knowledge, this is the first review article which has enclosed extensive information about the WCA and its applications.

Keywords: Water cycle algorithm (WCA) optimization algorithms
Artificial intelligence

1 Introduction

Among optimizations ways and means, metaheuristic approaches have proven their abilities in providing best solutions to real life problems, when the other methods sometimes are unable to provide the best solution of problems within a reasonable time. Especially, when several local minima hemmed in global minimum. The notions of such optimizer are usually motivated by observing natural phenomena. For example, Genetic algorithms (GAs) [1], simulated annealing (SA) [2], particle swarm optimization (PSO) [3], ant colony optimization (ACO) [4], are all inspired from nature [5].

The water cycle is a new optimization technique which has solved the many real-world problems; nowadays this algorithm has been widely using in different ways to address the complex problems. WCA was proposed by Eskandar et al. [6], which is employed in various constrained optimization and engineering contrive problems. The key concepts and celebrations which lie within the projected method is inspired by nature and based on the observance of water cycle process and precisely how rivers and streams flow towards the sea in the real world. However, there are abundant

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engineering optimization problems prevail in real-world, multifaceted and challenging to solve.

'Akin' to PSO algorithm the WCA is also a population-oriented and nature-inspired algorithm which introduces a unique metaheuristic method for optimizing coerced functions and engineering complications. The performance of WCA was examined on common constrained optimization problems, and the obtained results were matched with other optimizer's results regarding function number and evaluations. Furthermore, evaporation and raining process worked as mutation operator to prevent WCA from getting trapped in local optima [6]. Many researchers (Haddad and Moravej, et al. [7]; Lenin, Reddy, and Kalavathi [8]; Jabbar and Zainudin [9]; Guney and Basbug [10]; Sadollah et al. [11, 12]; Zhu et al. [13]) have used the water cycle in different ways to solve the complicated engineering optimization problem by utilizing WCA. The downsides regarding effectiveness and precision of prevailing numerical methods have stimulated scholars to depend on metaheuristics based on nature-inspired techniques to solve engineering optimization hitches. Therefore, this algorithm usually used by combining different rules of natural phenomena [14]. The evolutionary algorithms (EAs) are commonly known as common purpose algorithms within the optimization methods are acknowledged as to be most proficient in finding the near-optimum solution to the numerical real-valued test problems. EAs have been magnificently answered the constrained optimization problems. PSO performs multi-dimensional search and used the velocity vector to update the current position of each particle in the swarm [3].

The primary objectives of this article are to furnish the WCA broad applicability in various areas, as well as bringing it future challenges and opportunities. Up till the writing of this review article, there is no study which has provided the comprehensive review of WCA. Therefore, this study will provide the researchers a comprehensive discussion of the applicability and usability of WCA. Note that this article categorized the studies on WCA based on its modifications such as multi-objective-based, Gradient-based, and hybridizations as well as on its applications. So, this categorization aims at simplifying the understanding of the improving trends in the WCA.

2 Fundamental Structure of WCA

Nature speaks lots of secret languages, those who try to understand the nature's secret language make an invention in this world. Some nature-inspired optimization procedures have been established in the last two decades [15, 16]. Similarly, the idea of WCA was established on natural phenomenon, based on the observation of water how it completes its cycle naturally. To recognize this phenomenon, we should understand that how streams and rivers flow downhill towards the sea in the real world. The streams or rivers are formed when snow or glaciers melt at the top of the mountains. Then this stream or river flows downhill from one place to another, and their journey is eventually ending up in a sea. In this process of downhill, a lot of events occur such as rain and water's evaporation. During the evaporation, process water vanished away from lakes and rivers, while plants emit water in photosynthesis. In the atmosphere, this evaporated water converted into clouds and when these clouds smash with cold winds then they produce rain, and water again reached back to earth. This whole natural setup is known as the hydrologic cycle (water cycle) as presented in Fig. 1 [17]. To explore a new region of the search space evaporation and raining condition perform excellently and streams movement to exploiting the neighboring solutions. As a result, alteration of steps can affect the overall performance of WCA [18]. In order to employ WCA, required steps are explained as follows:

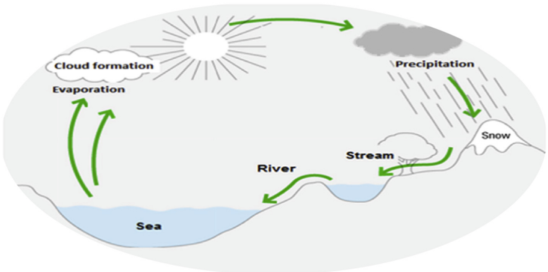


Fig. 1. Water cycle process in the real world by Deihimi et al. [19].

2.1 The Steps and Principles of WCA

Similar to many other metaheuristic algorithms, the WCA also starts with an initial population called raindrops. Suppose that we have rain, the best drop of rain will represent a sea, the sound raindrops are serving here like a river, and the rest of the raindrops are streams that flow into the rivers and seas. Depending on the size of the river represented in the subsequent each river take up water from the streams. Although, the amount of water in a stream that flows into rivers and the sea deviates from other streams. Also, rivers flow into the sea, which is the most downhill point on earth [6]. Below given Fig. 3 display the flow chart and Table 1 describes the fundamental steps of WCA.

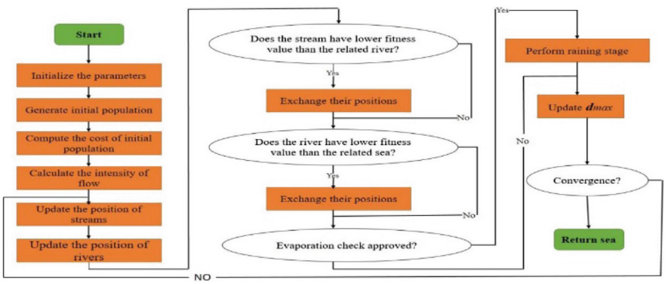


Fig. 3. Flowchart of the proposed WCA.

Table 1. Steps of WCA

Step 1: Selection of initial parameters

Select the initial parameters of the WCA: Nsr, dmax, Npop, max_iteration, etc.

Step 2: after the selection of initial parameters create initial population and streams by using Eqs. (2), (3), and (4).
In these given equations, stream, river and the sea demonstrate $1 \times N_{var}$ dimensional arrays, the solutions are defined as stream $= [x1, x2, x3, \ldots, xN]$ N_{sr} is the total number of rivers and sea, N_{stream} denotes a total number of streams.

Step 3: Estimate the value (cost) for each raindrop
The population size is represented here as N_{pop}. Some of the best solutions (N_{sr}) are deliberated as rivers, and the best river is taken as the sea in Eq. (5)

Step 4: Determine the intensity of flow for rivers and sea
As the following Eq. (6) is given: NS_n is the number of streams, which flow to the specific rivers or sea.

Step 5: Movement of streams and rivers
The movement of streams towards the rivers can be analyzed as given by Eq. (7). Where *rand* denoted as a uniformly distributed random number, and its value between 0 and 1. The exchange of positions will happen only when the solution provided by a *stream* is better than its joining *river*, then positions of *river* and *stream* are exchanged. Fig. 2 represents the exchanging of positions between the streams and rivers.

Step 6: Similarly, to step 5

The rivers move towards the sea which is the most downward place using Eq. (8).

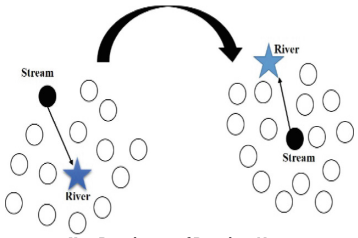
Step 7: The exchange of existing rivers with new picked up streams that offer the best possible value as shown in Fig. 2.

Step 8: this step is quite similar with Fig. 2, and the swapping of the position will be exactly same as step 7, if the solution given by a river is better than the sea then their positions will also be exchanged.
Step 9: *Evaporation condition*
Evaporation condition will help out to stay away from getting hem in local optimum solutions. The movement of the river towards the sea can be determined by this following Pseudocode.
In this pseudo code $d_{max}$is a small number which is close to zero. When the distance between river and sea is reached close to d_{max}, then it will be considered as that river/stream has joined the sea, and evaporation condition will be applied. A large value for d_{max} decreases the search while a small value encourages the search intensity near the sea. For that reason, d_{max} controls the search intensity near the sea. The value of d_{max}adaptively reduces as Eq. (9).
Step 10: The raining process will take place using Eqs (10), and (11) when the evaporation condition is contented as:
In Eq. (10), LB and UB are lower and upper bounds which are defined by a given problem. The μ represents the range of searching region, its value is 0.1, furthermore, in Eq. (11), $\sqrt{\mu}$ represents standard deviation, and 1 denoted the variance. By going through these steps, the created individuals with variance 1 are the best optimal solutions for the problem[6].

Step 11: By using Eq. (10) reduce the value of d_{max}. (10).

Step 12: In the last step, look at the convergence criteria. If the ending condition has fulfilled, then the algorithm will be stopped, if not return to Step 5.

$$Raindrop = [X_1, X_2, X_3, \ldots\ldots X_N] \quad (1)$$



$$X = \text{Population of RaindropNpops} = \begin{bmatrix} \text{RaindropNpop1} \\ \text{RaindropNpop2} \\ \text{RaindropNpop3} \\ \ldots \\ \ldots \\ \ldots \\ \text{RaindropNpop} \end{bmatrix} \quad (2)$$

$$N_{Sr} = \text{Number of Rivers} + 1$$
$$\text{Here } 1 \textit{ is a sea} \quad (3)$$

$$N_{Raindrops} = N_{pop} - N_{Sr} \quad (4)$$

$$\text{C}i = \text{Cost}i = \text{f}\left(x_1^i, x_2^i, \ldots\ldots x_{\text{N}var}^i\right)$$
$$i = 1,2,3, \ldots\ldots \text{N}pop \quad (5)$$

$$NS_n = round\left\{\left|\frac{Costn}{\sum_{i=1}^{Nsr} Costi}\right| \times N_{Raindrops}\right\},$$
$$n = 1,2,3, \ldots., N_{Sr} \quad (6)$$

$$X_{Stream}^{i+1} = X_{Stream}^{i} + rand \times C \times \left(X_{River}^{i} - X_{Stream}^{i}\right) \quad (7)$$

Fig. 2. Exchange of the positions among rivers and streams.

$$X_{River}^{i+1} = X_{River}^{i} + rand \times C \times \left(-X_{Sea}^{i} - X_{River}^{i}\right) \quad (8)$$

Pseudocode For Eveporation Condition

$$if \left|X_{Sea}^{i} - X_{River}^{i}\right| < d_{max} i = 1,2,3, \ldots\ldots.., N_{sr} - 1 end$$

$$d_{max}^{i+1} = d_{max}^{i} - \frac{d_{max}^{i}}{\max\ iteration} \quad (9)$$

Raining Process

$$X_{stream}^{new} = LB + rand \times (UB - LB) \quad (10)$$

And,

$$X_{stream}^{new} = X_{sea} + \sqrt{\mu} \times randn(1, N_{var}) \quad (11)$$

2.2 Constraint Handling and Convergence Criteria

Many studies emphasis on constraint handling strategies of metaheuristic algorithms [20]. In WCA, an improved feasible-based mechanism is introduced to control the problem specific constraints based on the following four rules [21].

Rule 1: Preference will be given to feasible solution instead of an infeasible solution.
Rule 2: A slight variation of infeasible solutions such as: (from 0.01 in the first iteration to 0.001 in the last iteration) is considered as feasible solutions.
Rule 3: Among two feasible solutions, the one holding better objective function value will be preferred.
Rule 4: Among two infeasible solutions, the one having the smaller sum of constraint violation will be preferred [22].

In metaheuristic algorithms it is also called as termination criteria, the best result is calculated when the termination condition can be considered as the maximum number of iterations, CPU time, or ε which is a small non-negative value and is demarcated as an acceptable tolerance between the last two results. Similarly, the WCA run until the maximum number of iterations as a convergence criterion is fulfilled [22].

3 Categories of Modified WCA

The study has divided the WCA into different categories based on the hybridization, modification, and structural and parametrically improvement of the algorithm. The following Fig. 4 describes that up to now how much percentage of studies have been conducted into these categories. For the performance enhancement of WCA, regarding its different aspects, many researchers have proposed different strategies and applied WCA into constrained problems. In this section detail of all these variants provided:

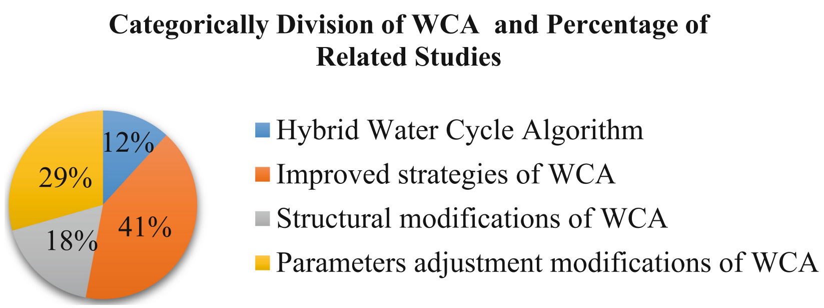


Fig. 4. Categorically division of WCA and percentage of related studies
Source: Data was collected from different online databases

'It was a big challenge to find studies related to WCA', owing to this, we have searched various databases such as Science-Direct, IEEE, Springer and Google-Scholar since 2012 to 2018 to overcome the thirst of WCA. As we know that the WCA was proposed in 2012 by Eskandar et al. [6], therefore in later years the importance of WCA research has been increased. Many researchers have focused on this metaheuristic with different perspectives of its modification and applications, the Fig. 5 demonstrate that how many studies have been conducted yearly and another category in the figure describes those other studies which have a close relationship to this review article.

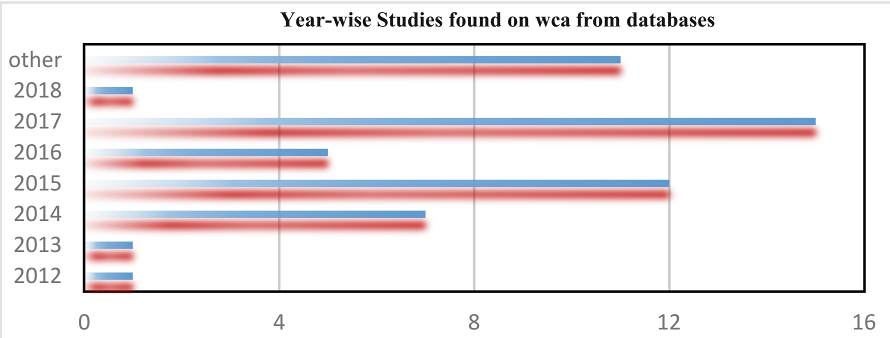


Fig. 5. Year-wise studies found on WCA from online databases

3.1 Hybrid WCA

Hybridization of algorithms have been carried out into many ways since a long time and this technique has been helped out the researchers to solve many constrained and complex engineering problems in the fields of information system analysis, artificial intelligence, decision-making systems, and data mining, etc., [23]. To improve the performance of algorithms hybridization technique applied by joining two methods. Similarly, WCA hybridization with other algorithm is a new hot trend in research, and some studies have improved its efficiency and feasibility such as:

Improved water cycle algorithm (IWCA) was proposed by Al-Saedi, [24] for attribute reduction in rough set theory(RST). The RST is considered as the primary source of attribute reduction and it is the most proficient tool for extracting useful knowledge and data. The study presented an improvement of WCA (IWCA) for rough set attribute reduction, by hybrid WCA with hill climbing algorithm to improve the exploitation process of the WCA. The results of the experiments revealed that the IWCA performs better than other methods of attribute selection.

Another hybrid technique was used by Khalilpourazari and Khalilpourazary [25] to increase the randomization and algorithm exploitation ability. WCA was hybridized with Moth-Flame Optimization (WCMFO) method, and this hybridized algorithm efficiently solved the engineering optimization problems. Based on the reviewed studies we can say that WCA has proven itself the best option for all those researchers/scientists due to its exploration and exploitation process.

3.2 Improved Strategies of WCA

Strategies are not algorithms, in the era of the common core, the evidence of change is all around us. Researchers improve the algorithm according to the nature of problems, they inject their idea and try to implement the new strategy in the existing algorithm. Furthermore, researchers have been improving different algorithms to reap the full benefits of their usability and applicability into different domains of life. Similarly, many scholars have also developed the WCA for resolving any problems related to different fields, such as:

Pahnehkolaei, et al. [26], proposed a Gradient-based WCA (GWCA) with evaporation rate. Its performance was testified by twelve well-known benchmark functions, which showed that GWCA has the ability to solve constrained problems efficiently. Dual-system WCA (DS-WCA) consists of two cycles, which are known as inner cycle and outer cycle. Therefore, it has the ability to perform exploration and exploitation process, which make it able to enhance population diversity and accelerate the convergence speed. Its performance was also compared with other famous metaheuristic techniques and it showed outstanding results regarding, speed, stability, and quality of solutions [27].

For power dispatch problems, Heidari [18] proposed a Gaussian bare-bones WCA (NGBWCA). It helps to alleviate the premature convergence and stagnation in local optima. Power dispatch has primary objectives to minimize the Resistive losses and voltage deviations. Owing to this, NGBWCA efficiency has compared on IEEE 30, 57 and 118 bus power systems. Remanufacturing rescheduling problems (RRP) can be solved by the discreet strategy provided by Gao, et al. [28] which called discrete WCA (DWCA). Authors have solved six real-life remanufacturing cases with different scales by DWCA. The obtained results of this metaheuristic specify the significance of the proposed DWCA strategy among other bi-objective algorithms.

Similarly, Qiao et al. [29], proposed an improved WCA with percolation behavior and the self-adaptive process of rainfall. It has the strong global searching ability and local optimization ability, which can effectively avoid all those deficiencies that conventional algorithms faced. Therefore, it is convenient and useful to solve multifarious optimization problems. Evaporation rate based WCA (ER-WCA), provides the better searchability than standard WCA. Because it keeps a fine balance between exploration and exploitation phases. Sadollah, et al. [5] Confirmed its results after comparing with standard WCA. Gao, et al. [30] strategically improved the WCA algorithm to solve the traffic scheduling problems, with another metaheuristic algorithm such as harmony search (HS) and Jaya algorithms.

3.2.1 Structural Modifications of WCA

Various amendments of the well-known algorithm have been proposed recently, which improve the empirical performance of the original algorithm by structural changes. Owing to this, some studies also have been conducted on the structural modification of the WCA such as:

Heidari [31] in an article contains chaotic patterns in stochastic processes of WCA to improve the performance of the conventional algorithm and to alleviate its premature convergence problem. Several chaotic signal functions, accompanied by various chaotically improved WCA strategies, are implemented, and the best signal is preferred as the most suitable chaotic technique for modifying WCA. The statistically exposed results that chaotic WCA with a sinusoidal map and chaotic-enhanced operators can not only utilize efficient high-quality solutions but can also surpass WCA optimizer and other investigated algorithms. Guney and Basbug (2015) [10] proposed a quantized WCA (QWCA) and used it for the antenna array pattern synthesis with low side-lobe levels (SLLs) and nulls at desired directions by using four-bit digital phase shifters. Moreover, QWCA has an internal quantization mechanism and a pre-calculated array factor method. The mechanism of the internal QWCA of quantification is used to achieve digital values that correspond to the different values of the phase slider rather than simply rounding up or down after optimization. The results of the quantized QWCA revealed to achieve good SLLs and null depth (NDLs) in the composite pattern, results are achieved in an exceptionally short optimization time. Sadollah, et al. [32] possesses unique structure, sandwich panels have special features that are most important with a high strength to weight ratio. Sandwich panels with different prism cores were researching, and the compared were performed for the quest for the best design. It was implemented WCA, the figures and results obtained to infer that the diamond prism topology was most effective in weight among other things existing designs under a certain load direction.

3.3 Parameters Adjustment Modifications of WCA

Parameters adjustment approach has been vitally acknowledged technique. The linear deviations in parameters are the most common, however, some other approaches also using nonlinear or stochastic functions. Owing to this, for the performance improvement, Méndez, et al. [33] introduced fuzzy based dynamic parameters adaptation, Oscar, et al. 2017 [34], used the intuitionistic fuzzy logic for the enhancement of WCA. its performance has been compared with other well-known states of the art functions. Furthermore, to solve the loss of power supply, maintenance and operations in power management system Sarvi, and Avanaki [35] used Water cycle algorithm and fuzzy logic controller. Rezk and Fathy, [36] developed an innovative approach for taking out the optimal parameters of PV module with high-efficiency InGaP/InGaAs/Ge triple-junction solar cells (TJSCc) which is based on WCA. Single diode model represents the TJSC model and then a constrained objective function has been derived to be used in the optimization process of optimal parameter estimation.

3.4 Logically Analysis of WCA Modifications

Dynamic performance of structures plays an important role in engineering; however, there are always some circumstances in which dynamic structural performance does not meet the design requirements or actual situations in practice. Therefore, it is common that some existing structures need to be modified to acquire desired dynamic performance [37]. Many researchers have put forward many methods for the algorithm's modification. Depending on the nature of the problem and understanding/ideas of the researchers/scientists' algorithm can be modified. As stated by reviewed studies which have been conducted on WCA it is noticed that WCA cannot be merely implemented for a specific engineering problem, although it can easily be modified according to the vibrant nature of problems. Above mentioned reviewed studies are the evidence for its applicability to real-life problems. WCA has performed successfully and efficiently in its all modified forms such as hybridization, structurally and strategically modification or parametrically modification. Furthermore, the WCA comparison has also been undertaken with all well-known metaheuristic algorithms. The obtained optimization results indicated the superiority of WCA against the existing metaheuristics. Following table-2 provides the information about the modified versions of WCA and related studies.

Table 2. Modified versions of WCA

WCA	Studies
Fuzzy based WCA	Méndez et al. [33], Sarvi and Avanaki [35]
Discrete WCA algorithm	Gao et al. [28], Guney and Basbug [10]
Dual-system WCA	Jahan [27]
Chaotic WCA	Heidari [31]
Gradient-based WCA	Pahnehkolaei et al. [26]
Evaporation rate WCA (ER-WCA)	Sadollah et al. [5]
Self-adaptive percolation behavior WCA (SPWCA)	Qiao et al. [29]
Hybrid WCAs	Al-Saedi [24], Khalilpourazari [25]

4 Applications of WCA

Owing to the WCA efficacies and applicability in real life, more and more researchers are working with it. Several studies have testified WCA application and appreciated its performance. In 2012, Eskandar, et al. [6] was proposed the water cycle algorithm Eskandar, et al. [6] proposed the original WCA in 2012 in which its performance evaluation was compared with other metaheuristics.

4.1 Application to Economics and Management Problems

Portfolio selection is considered one of the most important financial problem in the studies. Moradi et al., [38] solved the portfolio optimization problem with multi-objective water cycle algorithm, as well, for the optimal operation management Dei-himi, et al. [39], presented multi-objective uniform WCA. Both proposed techniques were testified by comparing the results with multi-objective particle swarm optimization, normal constraint algorithm, and non-dominated GA-II. To deal with supply chain management (SCM) problems e.g. to minimize the supply chain cost Khalilpourazari, [40] used WCA and presented a mathematical model of such problems. This is not only used for cost minimization, but it also can guide the flow of material and number of vehicles. Moreover, various test functions were used to evaluate the efficiency of the

WCA. In the SCM, supplier selection is one of the most challenging task purchasing management. WCA, artificial bee colony algorithm, and hybrid water cycle-artificial bee colony algorithm have potential to solve the SCM related problems efficiently [41]. In this regards, literature revealed that water cycle algorithm is the best choice for the engineers and managers among the other metaheuristics.

4.2 Applications to Engineering Problems

The potential advances in the use of evolutionary algorithms and metaheuristics in engineering applications bring an opportunity and also a challenge for researchers to improve and advance in design and optimization of products, systems, and services for societal benefits [42]. Keeping in the view some researchers have been successfully implemented the WCA into the engineering fields for solving NP-hard problems.

Multiprocessor scheduling problems are difficult task to perform because this process required a couple of excellent processors for operation. Nayak, et al. [43] used WCA to deal with the multiprocessor scheduling work. His study results revealed that WCA performs better than Genetic Algorithm (GA), Bacteria Foraging Optimization (BFO) and Genetic-based Bacteria Foraging (GBF). Large-scale urban traffic light scheduling problem (LUTLSP), was efficiently handled by three metaheuristics techniques such as Jaya algorithm, harmony search and WCA [30]. Sadollah, et al. [32] stated that to find the best design and weight ratio, diamond prismatic topology is the best solution for truss and sandwich panels structure. Truss structures optimization problems considered as a most complex problem in the engineering field. A study conducted by Sadollah, Eskandar, et al. [44] revealed that nature-inspired algorithm could solve the truss structure problems proficiently than other traditional methods. They used the mine blast algorithm (MBA), improved mine blast algorithm (IMBA) and WCA to solve such problems. The proficiency of IMBA, WCA, and MBA was studied using four truss structures. Optimization results revealed that nature-inspired algorithms are more efficient in handling the engineering design and weight measurements problems.

Moreover, combinatorial nonlinear optimization problems such as Water distribution system (WDS) design optimization problems also can solve with the help of WCA. Water cycle combined with the hydraulic simulator and EPANET has applied for finding the optimal cost design of WDS. The study results have been verified by other states of the art algorithms [45].

4.3 Applications to Power and Energy System Problems

Over a decade, electricity production will be a major concern in the world, especially for Lanners in the field of electro-technology, where the increase in electricity demand has led to a more and more electricity market liberal and very Competitive. The main objective is to generate a total electrical production of all producing units at the lowest possible cost, taking into account the satisfaction of the total tax requirement and the fulfillment of the Production capacity of all units of production in energy [19]. This requires the proper design, operation, and control of the electricity produced by each production unit. Therefore, this task can be defined as a problem with the as Economic Dispatch (ED) and listed as a constraint optimization problem.

Deihimi et al. [19], Ashouri and Hosseini [46], and Naveed et al. [47] has applied the WCA algorithm, or resolving Economic Load Dispatch (ELD) problem. The WCA optimized results are the evidence for dealing with complex ED problems. Moreover, Optimal reactive power dispatch (ORPD) and Optimal power flow (OPF) considered as most crucial tools in power system operations. Heidari, [18] recommended a Gaussian bare-bones WCA (NGBWCA), and Barzegar, et al. [48] utilized standard WCA for dealing with ORPD and OPF problems respectively.

Elhameed, and El-Fergany, [49] offered a useful methodology based on WCA for the resolution of unique and multiple objectives of the economic load dispatch (ELD) to produce the best current energy value generated for each unit. The proposed methodology based on WCA has shown in three cases of tests with different complications and under a series of objective scenarios. The numerical results and subsequently compared with other provocation optimizers indicate the viability and confirm the potency of the proposed WCA method.

Furthermore, El-Hameed, and El-Fergany, [50] solved the problem of the multi-area interconnected power system by utilizing the WCA methodology with load frequency controller. WCA efficiently generate the optimal alteration for 'proportional–integral–derivative' and Ziegler–Nichols PID tuning methods which have confirmed the impact of the proposed strategy. For the optimization multi-reservoir systems Yanjun, et al. [51] suggested an enhanced version of water cycle algorithm, and its results compared with standard WCA and WCA with evaporation rate. Simulation-based results demonstrated that proposed strategy could be efficiently utilized in this field. To find the optimal parameters of Power system stabilizers (PSS), it is also noted that WCA can find out the optimal parameters for PSS proficiently concerning computational time to increase the power system stability [52].

Kler, et al. [53] researched to investigate precise performance and control of photovoltaic (PV) systems. Therefore, they have applied 'Evaporation Rate based WCA' for useful parameters estimation of PV cell/module under varying temperature and irradiation conditions.

Hydro-thermal scheduling is an essential step in the work planning of the electrical system. It is coordinated between the performance of Hyde and the heat machine so that the cost of producing electricity is minimal under the satisfaction constraints. Due to that reason, Haroon and Malik [54] carry out research on Evaporation Rate-Based WCA for Short-Term Hydrothermal Scheduling. Their study results demonstrated the advantage of ER-WCA over the other metaheuristic algorithm.

4.4 Analysis Based on the Applications of WCA

WCA has potential to solve the constrained optimization and engineering design problems efficiently. Although this is recently proposed an algorithm, it still has successfully implemented into different domains, for example, Economics and Management, Engineering, power, and energy system. Studies carried out on the applications of WCA indicated that WCA has been solved the complex nonlinear problems such as water distribution, portfolio optimization, economic load dispatch problems, electric power system, truss structure design and supply chain management problems very efficiently and effectively. Based on the reviewed studies results have been compared with other metaheuristics which have authenticated and testified the WCA. Following are the examples of WCA success and efficiency:

1. To find the best pipe diameter sizes for minimizing the construction cost. Comparison with other reported algorithms has been carried out regarding the optimized statistical value and computational efforts (i.e., number of function evaluations). Based on the obtained optimization results, the WCA offered cheaper design (i.e., configuration of pipe diameters) compared with other optimizers ($295,000 saving money) having faster convergence rate [45].
2. Dihem, et al. [19], Ashouri and Hosseini [46] studies are related to ED problem considering practical constraints of generating units. The effectiveness of the 'WCA' has been reconnoitered on three test systems with different convolution and scales, compared to the objective function, the cost of fuel has both types of curves smooth and non-smooth respectively. Substantiated the results of simulations for complex ED problems that present the best properties of solutions in comparison with another set of rules.
3. The study related to job-shop scheduling problem analysis using the WCA technique in the universal optimization of flexible job-shop problem exhibited that the proposed algorithm in cost function was able to get hold of the best solution in the problem than the other different approaches in the literature [27].
4. Gao, et al. [30] solved a large-scale urban traffic light scheduling problem (LUTLSP). The evaluations and dialogs verify that the WCA methods can successfully explain the LUTLSP significantly superior the existing techniques.

So far the majority of the studies have been conducted in the field of power and energy system, which are the evidence of WCA superiority. Although many studies also held in the area of Engineering, Economics, and Management there is still a dire need to do more. Following given table-3 describes those studies which have been carried out on specific application areas of WCA.

Table 3. Application areas of WCA

Area	Studies
Economics and management	Moradi et al. [38], Deihimi et al. [39], Khalilpourazari [40], Praepanichawat [41]
Engineering problems	Nayak et al. [43], Gao et al. [30], Sadollah et al. [32], Sadollah [45], Sadollah and Eskandar et al. [44]
Power and energy system problems	Dihem et al. [19], Barzegar et al. [48], Elhameed and El-Fergany, [49], El-Hameed, and El-Fergany [50], Yanjun and Yadong et al. [51]

5 Conclusions and Discussion

About the reviewed articles, it will be appreciated that WCA has been mostly applied in solving massive optimization problems. After reviewing the studies which have been resolved the economics and management problems it is noted that WCA has not only performed better than the traditional approaches, it has also provided the best and efficient results.

In General, a fundamental feature of meta-heuristics is exploitation (intensification) and exploration (diversification). Exploitation to keep track of information from the best current solutions, looking for the end of the current solution and choose the best candidate. While the exploration characteristic ensures that you further explore the search space, as it is can often diversify with several random strategies that are essential for an algorithm to jump out of some local Optima. WCA is an easy to implement and easy to modify according to the nature of the problem. WCA has a comparative advantage over traditional metaheuristic algorithms, as another metaheuristic algorithm quickly falls into their local optimum solution such as PSO. WCA avoids getting trapped in the local optimum solutions due to its evaporation condition and raining process. WCA convergence speed has been more improved by a new self-adaptive WCA with percolation behavior approach. Simultaneously, a self-adaptive rainfall process can generate the new stream, more and more new position can be explored, consequently, increasing the diversity of the population. The improved WCA can efficiently utilize to various multifarious optimization tasks in diverse areas of sciences and technologies. The MOWCA was used to solve some distinguished benchmark and engineering Mops. The efficiency and performance of the MOWCA were demonstrated using three standard criteria (i.e., generational distance, metric of spacing, and spread metric). The MOWCA offers competitive solutions compared with other population-based algorithms.

The article summarizes the review of "WCA' studies, as mentioned above in Tables 2 and 3, where 'WCA' publications on various areas of application, modification and hybridization to various formulations of combined optimization problems have been listed. Based on these tables, we can see that the growth of this algorithm develops rapidly, despite the fact that its proposition is about five years. So far, most researchers have focused on solving energy and energy problems with 'WCA', and it provides very superior results among others metaheuristic algorithms. According to the articles examined, it can be analyzed that the literature still has a thirst for studies focusing on WCA applications and modifications in several disciplines. Many improved WCA tackles the constrained problems very efficiently such as:

1. The ER-WCA shows its potential for tackling constrained problems by providing better statistical optimization results in a fewer number of function evaluations compared with the considered optimizers. It can the global minimum of multimodal functions with minimum possibility of getting trapped in local minima.
2. NGBWCA can be applied to other global optimization problems, especially engineering optimization problems.
3. The Multi-objective version of WCA (MOWCA) for solving unconstrained and constrained multi-objective optimization problems.

4. Hybrid water cycle-artificial bee colony algorithm (HWAA) introduced to find the optimal solutions for optimal order allocation problem.
5. The self-adaptive process of rainfall can generate the new stream, more and more new position can be explored, consequently, increasing the variety of population.

In future, some studies should be conducted on

1. Hybridizing of PSO and WCA, GA or DE and WCA, and ACO and WCA. Such studies can provide much stronger evidence for solving linear or non-linear problems. It is expected that new technique obtains high-quality solutions in tackling constrained and unconstrained problems and some applications, for example, training of neural networks (NNs).
2. Hence, researchers should still focus on this algorithm for the implementation in other fields to solve the complex problems.
3. The proper utilization of 'WCA' can be more helpful in all fields of engineering and optimization. The researchers should try to implement it for various complex optimization problems.
4. Further investigation of this algorithm by its adaptation to other domain, which adjustment of control parameters and theoretical studies should be explored in the next future. Overall literature shows that not much work was done on the theoretical aspects of the WCA, it would be interesting to perform a theoretical study of runtime and convergence nature of this algorithm.

As a final point, this study conducted an efficient, far-reaching review to get hold of the relevant literature on the applications, modifications, and hybridizations of the WCA when applied to solve problems of high dimensionality in the different domain. This comprehensive review will be advantageous for the researchers, literature, and community. In addition to for those are working or want to research this domain. In conclusion, there are still many exciting and innovative research directions where WCA deployment can be helpful for optimization problems.

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