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OPTIMIZATION OF WATER DISTRIBUTION NETWORKS USING ENHANCED HEURISTIC SWARM INTELLIGENCE ALGORITHM

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Abstract: In this paper, an optimal water distribution network (WDN) model was developed. An existing metaheuristic algorithms, known as the particle swarm optimization (PSO) algorithm was applied on the model to obtain the optimal cost of water distribution. A modified form of PSO called the enhanced heuristic swarm intelligence (EHSI) algorithm was also constructed and used to solve the model. Three case studies were treated. Results obtained show that PSO and EHSI algorithms minimize the total cost of water distribution network using the designed model and the EHSI algorithm performs better than PSO algorithm. **present a detailed comparison of result of PSO and HSI algorithm.**

Keywords: Water Distribution Network, optimization, heuristic swarm intelligence

1. INTRODUCTION

The high investment and maintenance cost associated with both new water distribution networks and the expansion of existing ones had led mathematicians and engineers to take great interest in consulting mathematical methods to find their optimal design, that is the network with minimum cost. In practice, the optimization can take numerous forms depending on the various kinds of components which comprise a water supply systems, the diverse criteria for the correct functioning, and the design constraints of such a network, [1].

Over the last two decades, a large number of optimization models have been developed. Few of them attempted to obtain the optimal layout, [2-5]. Any water supply system should be able to transport portable water from a certain tank to the consumer. A water distribution network (WDN) is the most important element in such a system, consisting of a piping system, as well as devices made of pumps, valves, tanks, meters, among other accessories. The efficient and continuous delivery of water in adequate quantity, quality, and pressure to the consumer must be guaranteed. Great investments are made throughout the world to provide or update water supply systems efficiently [6-9]. Even so, a large part of the population has no access to adequate WDN. Setting up the WDN begets most of the costs of a water supply system [10-15] The WDN optimization problem is a complex one, due to practical considerations. The diameters of the pipes should be selected from a set of available ones and, as such, cannot be considered as continuous variables. Furthermore, because pipe diameters are discrete variables, there is additional complexity [10]. The analytic solution to this problem is a complex one, as it simultaneously involves equations for conservation of mass and energy, head losses, and the minimum network requirements such as minimum pressures at demand nodes and flow velocities, which should stand between the minimum and maximum limits imposed by the problem. An optimum WDN design involves finding the diameter of each network pipe so that its total cost is minimized within the hydraulic constraints [16].

One of heuristic algorithms used for solving optimization problems is the particle swarm optimization (PSO) algorithm. In PSO Algorithm, every solution of the optimization problem is regarded as a bird in the search space, which is called a particle. Every particle has a velocity by which the direction and distance of the flying particle are determined. Particle swarm optimization algorithm was first introduced by [17-19], by observing the behavior of animals, e.g. birds flocking and fish schooling. Their movements and communication mechanisms were thoroughly studied, 20. In comparison with several other population-based stochastic optimization methods such as Genetic Algorithm(GA) and evolutionary programming(EP), PSO performs better in solving various optimization problems with fast and stable convergence rate. Recent advancements in PSO have focused on hybrid approaches and adaptations for specific applications. For example, [21] proposed a hybrid PSO algorithm combined with differential evolution, achieving superior performance in solving benchmark optimization problems. [22] introduced a novel adaptive PSO variant tailored for real-world engineering problems, demonstrating its robustness and adaptability in dynamic environments. Similar studies can be found here [23-26]. The parameter involved in the PSO are listed in the table below.

Table 1.1: Parameters Involved in PSO Algorithm

Parameter	Definition
c_1, c_2	PSO constants, mostly given as 2
$Itmax$	The maximum number of iterations
$iter$	The number of current iteration
w	Inertia weight
w_{max}	Maximum inertia weight
w_{min}	Minimum inertia weight
x_i	Position of particle i
N_p	Total number of particles
x_i^{t+1}	The position of particle i at $(t+1)^{th}$ iteration
x_i^t	The position of particle i at $(t)^{th}$ iteration
v_i^{t+1}	The velocity of particle i at $(t+1)^{th}$ iteration
$P_{best,i}^{t+1}$	The personal best of particle i at $(t+1)^{th}$ iteration
$G_{best,i}$	The global best
r_1, r_2	Random variables, which are always between 0 and 1

The algorithm of PSO is given below:

Step 1: Initialize the population size N_p, the dimension of the space

$c_1, c_2, It_{max}, w_{max}$ and w_{min}

Step 2: Set $P_{best,i} = x_i$, $(i = 1, \ldots, N_p)$

calculate the fitness of x_i

Find G_{best}

step 3: If $iter < It_{max}$

Step 4: Calculate the inertia weight

$$w = [w_{max} - \frac{w_{max} - w_{min}}{It_{max}}(iter)]$$

Step 5: Calculate the velocity of each particle by

$$v_i^{t+1} = wv_i^t + c_1 r_1 (P_{best,i} - x_i^t) + c_2 r_2 (G_{best} - x_i^t)$$

Step 6: Calculate the position of each particle by

$$x_i^{t+1} = x_i^t + v_i^{t+1}$$

Step 7: Calculate the value of the objective function for each particle

$$f(x_i^{t+1})$$

Step 8: Find $P_{best,i}^{t+1}$ and G_{best}

if $f(x_i^{t+1}) > P_{best,i}^t$ then $P_{best,i}^{t+1} = P_{best,i}^t$

else

$P_{best,i}^{t+1} = x_i^{t+1}$

Step 9: Go to step 3.

A water distribution network (WDN) is usually represented by a graph with vertices (nodes) and edges (pipes) connected at the vertices. The nodes may represent tanks or demand nodes, while the lines may represent pipes, valves, or pumps. The WDN optimization problem can be formulated using mixed-discrete nonlinear programming (MDNLP) with the diameters of each pipe as the decision variables, which are real-valued and discrete. In the 1970s, researchers approached the WDN optimization using linear, non-linear, dynamic, and mixed-integer programming methods. An iterative method named linear programming gradient (LPG) method was introduced by [5], which involves two steps. The first step consists of considering optimization of design when the distribution of flow rates in the network is assumed to be known and the second one consists of calculating the length of pipes with normalized diameters belonging to a certain part of the network. Particle swarm optimization concept in terms of its precursors, briefly reviewing the stages of its development from social simulation to optimizer was proposed by [6]. Results obtained from applications was shown to perform successfully. A new parameter called inertia weight was introduced to the velocity of the standard particle swarm optimization by [7], in which the stated velocity ranges from (0.9m/s to 1.2m/s) after simulation. Therefore it is concluded that the modified PSO performs better than the standard PSO. A water distribution network model was designed by [8] and solved by using a heuristic algorithm called simulated annealing and the efficiency of the model was tested by two benchmark networks, namely Alperovits and Shamir network and Hanoi network.

A modified genetic algorithm for water distribution network optimization was proposed by [2], in which at each generation some constant number of solutions were allowed to undergo at most one mutation. This modified genetic algorithm was tested on the New York City water supply expansion problem. A method for optimizing the design of water distribution model under the required demand loading and hydraulic condition was designed by [9] and an optimization model was formed which was solved by LINGO 13.0 software.

A modified particle swarm optimization using the last-eliminated principle approach was proposed by [10]. This modified PSO was named improved and enhanced particle swarm optimization (IEPSO). IEPSO effectively eliminated the premature convergence and tendency to fall into local optimum and enhanced the local global information sharing capability to improve its global optimization performance. An improved particle swarm optimization algorithm based on last eliminated principle enhanced information sharing was also proposed by [10]. A novel swarm intelligence optimization approach called sparrow search algorithm which focuses on foraging and predation behaviours of sparrow birds was proposed by [11]. These behaviours were presented in optimization techniques and were compared with other metaheuristic optimization algorithms and swarm intelligence optimization techniques after testing the searching precision, convergence, speed and stability with 19 test functions and two engineering models.

In all the literature encountered, none addressed the velocity of flow in pipe and the cross-sectional area of the pipe. Also the mateheuristic algorithms in literature were trapped by local optimum. Therefore in this work a water distribution network (WDN) model which considers the velocity of flow in pipe and cross-sectional area of pipe was developed. Particle swarm optimization algorithm (PSO) was used to solve the model. A new modified particle swarm optimization algorithm known as enhanced heuristic swarm intelligence algorithm was developed and also used to solve the model.

2. MODEL FORMULATION

In this work a water distribution network model was formulated as a least-cost optimization problem which determines the optimal pipe sizes. The pipe layout and its connectivity, nodal demand, and minimum requirement of pipe length, diameter and flow are assumed known. The water distribution network model must obey the governing principles of water distribution as stated below: Principle of Water Distribution Model

(a) Conservation of Mass (Continuity Equation)

The algebraic sum of flow rates in the pipes meeting at a junction, together with any external flow is zero;

(b) Conservation of Energy

The conservation of energy implies that conceptually the head losses through the system must balance at each point. For pressure networks, this means that the total head loss between any two nodes in the system must be the same regardless of what path is taken between the two points. The head loss must be sign consistent with the assumed flow direction (i.e. gain head when proceeding opposite the flow and lose head when proceeding with the flow), Ayanniyi *et al* (2013).

2.1 *Construction of the New Water Distribution Model*

The parameters involved in the water distribution network are presented in Table 2.1 below:

Table 2.1: Parameters Involved in the Model and their Meaning

Parameter	Definition
E	Cost coefficient
C_T	Total cost of network
L_k	Length of pipe k
D_k	Diameter of pipe k
m	Exponent obtained by regression analysis/regression coefficient
A_k	Cross section area of pipe k
V_k	Fluid velocity in pipe k
M_j	Demand at node j
N	Total number of nodes in the network
U	Total number of pipes
R	Constant depending on pipe material
β	Exponent relating head loss to flow rate
γ	Exponent relating head loss to velocity
h^{min}	Minimum residual pressure allowed
M^{min}	Minimum demand
L^{min}	Minimum pipe length
D^{min}	Minimum diameter
V^{min}	Minimum velocity
A^{min}	Minimum cross sectional area

Applying the governing principle of water distribution model the new model is constructed as follows: The objective function is the total cost of the materials used in setting up the system. For each pipe k the cost is given by

$$C_k = EL_kD_k^m, \qquad (1)$$

where C_k is the cost of network at pipe k, E is the cost coefficient, L_k is the length of pipe k , D_k is the diameter of pipe k, m is the exponent obtained by regression analysis, we assume that the cost of a pipe varies linearly with length.

Suppose there are U pipes, the objective function is the total cost of the network which is given by

$$C_T = \sum_{k=1}^{U} EL_kD_k^m \quad . (2)$$

Hence the optimization problem to be solved becomes:

Minimize

$$C_T = \sum_{k=1}^{U} EL_kD_k^m \quad , \quad (3)$$

subject to the following constraints:

(a) Loop head constraint

(4)

The head loss along links around each loop must be balanced, that is the algebraic sum of head loss along links around each loop must be zero.

This implies that

$$\sum_{k=1}^{U} RL_k(A_kV_k)^{\beta}D^{-\gamma} = 0 \qquad (4)$$

where $R = \frac{\alpha}{(C_{HW})^{1.85}}$

The value of α is given to be $2.234\text{x}10^{12}$ by [12] and $C_{HW} = 130$ for Unplasticized Polyvinyl Chloride (UPVC) and the value of α is $2.234\text{x}10^{12}$ [12]

C_{HW} is roughness coefficient.

Therefore

$$R = \frac{2.234(10^{12})}{130^{1.85}} = 2.74(10)^8; \qquad (5)$$

(b) Continuity equation/node flow continuity constraints

The node flow continuity equation requires that at each node, the total inflow must be equal to the total outflow. This implies that the algebraic sum of flow along the links to each node must be equal to zero. Applying this we obtain

$$\sum_{k=1}^{U} A_k V_k + \sum_{j=}^{N} M_j = 0, \qquad (6)$$

where M_j is the demand at node j and N is the total number of nodes ;

(c) Path head loss constant

The head loss in links along the N paths to each node must not be greater than the minimum pressure.

This implies that

$$\sum_{k=1}^{U} RL_k (A_k V_k)^{\beta} D^{-\gamma} \leq h^{min}, \qquad (7)$$

where h^{min} is the minimum residual pressure allowed ;

(d) Non-negativity constraints

This gives the boundary constraints for the decision variables and it leads to the following inequalities

$$L_k \geq L^{min} \qquad (8)$$

$$D_k \geq D^{min} \qquad (9)$$

$$V_k \geq V^{min} \qquad (10)$$

$$A_k \geq A^{min} \qquad (11)$$

The new model is therefore given by (3) subject to (4), (6), (7),...,(11). In order to complete the construction of the model, the cost coefficient E and the exponent m are needed.

A market survey for pipe materials was constructed and the summary of the data obtained is presented in Table 2.2 below.

Table 2.2 : Diameter and Cost Relationship (Ilorin pipe market**)**

S/N	Diameter(mm)	Thickness(mm)	Length(m)	Cost(N)	Unit cost (N/m)
01	20	3	6	624	104
02	25	3	6	750	125
03	32	3	6	1250	208
04	40	3	6	1500	250
05	50	3.7	6	2300	383
06	63	4.7	6	3400	566
07	75	5.6	6	4500	750
08	90	6.7	6	6600	1133
09	110	8.2	6	9000	1500
10	160	11.9	6	19000	3167
11	225	16.7	6	43500	7250
12	315	19.1	6	92000	15333

The information given in Table 2.2 is presented graphically is Figure 1 below.

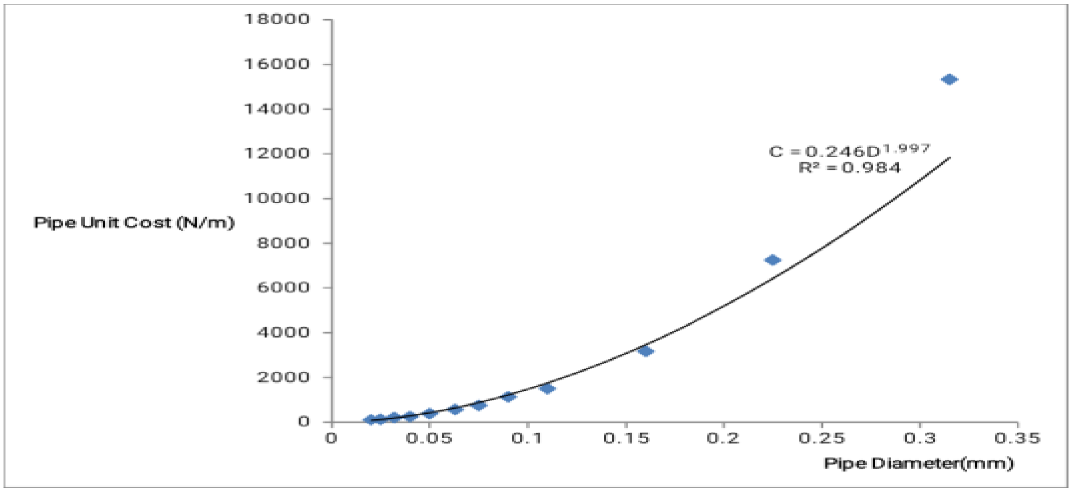

Fig 1: Diameter and Cost Relationship for Pipes

From Table 2.2 the cost coefficient was computed to be 0.246 while the regression coefficient m was 1.997

2.2 The Enhanced Heuristic Swarm Intelligence (EHSI) Algorithm

Just like other metaheuristic algorithms, PSO converges prematurely and is trapped into a local minimum. In other to overcome this difficulty, this paper constructs a modification of PSO algorithm named Enhanced Heuristic Swarm Intelligence (EHSI) algorithm.

The parameters used in the new algorithm are given in table 2.3 below.

Table 2.3:Parameters Involved in EHSI Algorithm

Parameter	Definition
c_1, c_2	PSO constants, mostly given as 2
$Itmax$	The maximum number of iterations
$iter$	The number of current iteration
w	Inertia weight
w_{max}	Maximum inertia weight
w_{min}	Minimum inertia weight
x_i	Position of particle i
N_p	Total number of particles
x_i^{t+1}	The position of particle i at $(t+1)^{th}$ iteration
x_i^t	The position of particle i at $(t)^{th}$ iteration
v_i^{t+1}	The velocity of particle i at $(t+1)^{th}$ iteration
$P_{best,i}^{t+1}$	The personal best of particle i at $(t+1)^{th}$ iteration
$G_{best,i}$	The global best
r_1, r_2	Random variables, which are always between 0 and 1
r_3	Random variables, which are always between 0 and 1
b	a small number
C_k	Cost of network at pipe

In this algorithm the natural log of the inertial weight (w) of PSO was considered as the inertia weight of the algorithm i.e.

$$w = ln(w_{max} - \frac{w_{max}-w_{min}}{It_{max}}(iter)) \tag{12}$$

Also a disturbing term is introduced to the velocity of particles in PSO. This disturbing term $|b(r_3 - 0.5)|$ is introduced to the velocity, where b is a small number and r_3 is a random variable in the range $(0,1)$. We take $b = 0.05$ in this paper. Therefore the velocity of each particle was updated with

$$v_i^{t+1} = wv_i^t + c_1 r_1 (P_{best,i}^t - x_i^t) + c_2 r_2 (G_{best} - x_i^t) + |b(r_3 - 0.5)| \tag{13}$$

Algorithm of the Enhanced Heuristic Swarm Intelligence (EHSI)

(13)

Step 1: Initialize the population size N_p, the dimension of the space

$c_1, c_2, It_{max}, w_{max}, w_{min}$

Step 2: Set $P_{best,i} = x_i$, $(i = 1, \ldots, N_p)$

calculate the fitness of x_i

Find G_{best}

step 3: If $iter < It_{max}$

Step 4: Calculate the inertia weight

$$w = ln(w_{max} - \frac{w_{max}-w_{min}}{It_{max}}(iter))$$

Step 5: Calculate the velocity of each particle by

$$v_i^{t+1} = wv_i^t + c_1r_1(P_{best,i}^t - x_i^t) + c_2r_2(G_{best} - x_i^t) + |b(r_3 - 0.5)|$$

Step 6: Calculate the position of each particle by

$$x_i^{t+1} = x_i^t + v_i^{t+1}$$

Step 7: Calculate the value of the objective function for each particle

$$f(x_i^{t+1})$$

Step 8: Find $P_{best,i}^{t+1}$ and G_{best}

if $f_i^{t+1} > P_{best,i}^t$ then $P_{best}^{t+1} = P_{best}^t, i$

else

$$P_{best,i}^{t+1} = x_i^{t+1}$$

Step 9: Go to step 3.

2. IMPLEMENTATION OF THE CONSTRUCTED MODEL

Case study 1

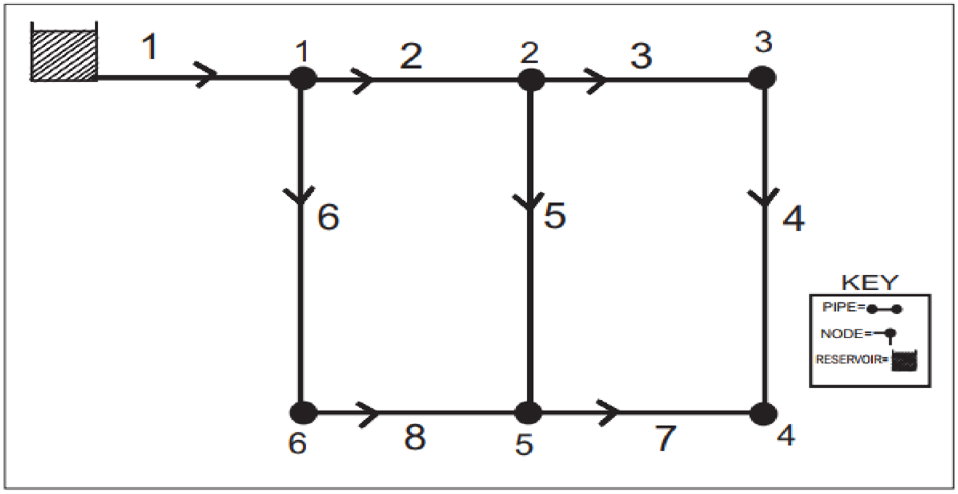

Fig 2: Pipe Network layout for Yalu street, Gaa Akanbi, Ilorin.

Case study 1 is the network layout for Yalu street, Gaa Akanbi, Ilorin, which comprises eight(8) pipes and six(6) nodes as shown in figure 3.1. The head losses were calculated using Hazen-Williams equation and every diameter has a dimensionless roughness coefficient C equal to 130 with the data given in Table 3.1

Table 3.1: Geometric data of network layout for Yalu street, Gaa Akanbi, Ilorin.

pipe	pipe length(m)	pipe diameter(mm)	flow along the pipe (l/s)	cost of network($Naira$)
1	100	152	0.474	421,220
2	125	101	0.593	320,510
3	130	127	0.616	335,140
4	134	76	0.635	213,810
5	100	127	0.474	421,220
6	125	101	0.593	560,000
7	110	127	0.521	450,000
8	100	101	0.474	350,000
Total				3,071,900

*Source:Kwara State Water Corporation

Using Epanet to simulate the Water Distribution Network data in Table 3.1 the values in Table 3.2 were generated.

Table 3.2: Demand at Nodes of Case Study 1.

node	node demand (l/s)
1	0.57
2	0.41
3	0.31
4	0.32
5	0.42
6	0.32

The minimum pressure generated after the simulation by Epanet is 3.51

In solving this model with the case studies using PSO and EHSI algorithm, we will take the following values for the PSO and EHSI parameters

$w_{max} = 0.9$
$w_{min} = 0.4$
$It_{max} = 1000$
$b = 0.05$
number of particles=100
where m=1.997, obtained from figure 2.1 so we have

$$C_T = ELD^{1.997} \tag{14}$$

3.1 Solution to case study 1

After the implementation of case study 1 using the designed model and solved with PSO and EHSI the results in Table 3.3 and Table 3.4 below were obtained.

Table 3.3: Result of Case Study 1 obtained using PSO

pipe	pipe diameter(mm)	pipe cross-section area(m^2)	velocity of flow (m/s)	cost of network($Naira$)
1	70	2.0000	0.100	119,010
2	70	1.1287	0.100	148,770
3	70	0.2000	0.100	154,720
4	70	2.0000	0.100	159,480
5	70	2.0000	0.100	119,010
6	70	2.0000	0.100	148,770
7	70	2.0000	0.100	130,910
8	70	2.0000	0.100	101,901
Total				1,099,700

Table 3.4: Result of Case Study 1 obtained using EHSI

pipe	pipe diameter(mm)	pipe cross-section area(m^2)	velocity of flow (m/s)	cost of network($Naira$)
1	70.0	0.2000	0.1000	119,010
2	70.0	0.2051	0.1000	148,770
3	67.5	0.2038	0.100	143,880
4	70.0	2.0000	0.1000	159,480
5	68.0	2.0000	0.4995	112,320
6	70.0	2.0000	0.5000	148,770
7	69.5	2.0000	0.5000	129,050
8	70.0	2.0000	0.5000	119,010
Total				1,080,300

Case study 2

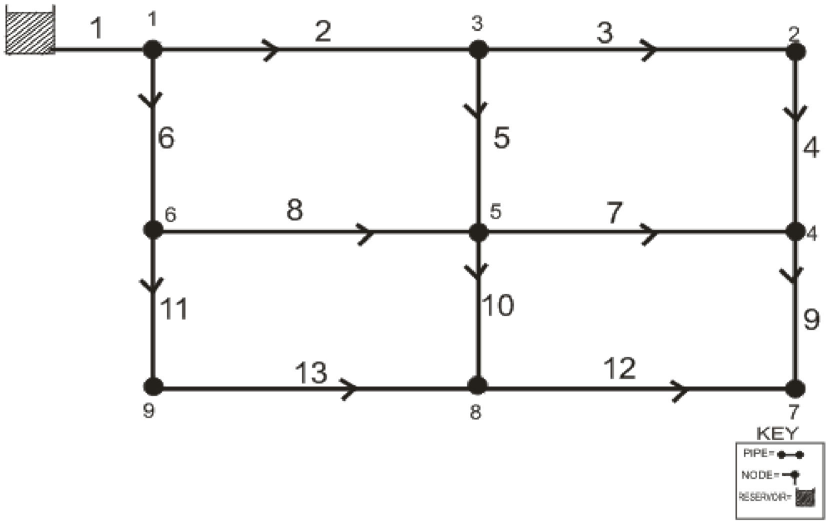

Fig 1: Pipe Network Layout for Gaa Odota, Ilorin.

Case study 2 is the network layout for Gaa Odota, Ilorin, which comprises thirteen(13) pipes and nine(9) nodes as shown figure 3.2. The head losses were calculated using Hazen-Williams equation and every diameter has a dimensionless roughness coefficient C equal to 130 with the data given in Table 3.5

Table 3.5: Geometric Data of Network Layout for Gaa Odota, Ilorin

pipe	pipe length(m)	pipe diameter(mm)	flow along the pipe (l/s)	cost of network($Naira$)
1	150	200	0.472	950,100
2	120	100	0.366	120,000
3	100	200	0.305	811,110
4	100	190	0.305	800,000
5	130	200	0.397	801,100
6	125	100	0.381	1,095,000
7	120	200	0.365	1,222,000
8	155	115	0.473	900,000
9	110	100	0.336	812,200
10	150	200	0.458	1,533,100
11	150	200	0.458	563,450
12	130	200	0.397	450,445
13	100	200	0.305	999,100
Total				11,057,605

*Source:Kwara State Water Corporation

Table 3.6:Demand at Nodes of Case Study 2

node	node demand (l/s)
1	0.45
2	0.40
3	0.35
4	0.30
5	0.40
6	0.38
7	0.24
8	0.50
9	0.38

The minimum pressure generated after the simulation by Epanet is 4.25

3.2. Solution to case study 2

After the implementation of case study 1 using the designed model and solved with PSO and EHSI the results in Table 3.7 and Table 3.8 below was obtained.

Table 3.7: Result of Case Study 2 obtained using PSO

pipe	pipe diameter(mm)	pipe cross-section area(m^2)	velocity of flow (m/s)	cost of network($Naira$)
1	95	2.0000	0.1000	328,500
2	95	2.0000	0.1000	262,800
3	95	0.2000	0.1000	219,000
4	95	0.2000	0.1000	219,000
5	95	0.2000	0.1000	284,700
6	95	0.2000	0.1000	273,750
7	95	0.2000	0.1000	262,800
8	95	2.0000	0.1000	339,450
9	95	2.0000	0.1000	240,900
10	95	1.6373	0.1000	328,500
11	95	2.0000	0.1000	328,500
12	95	0.2000	0.1000	284,700
13	95	0.2000	0.1000	219,000
Total				3,591,600

Table 3.8: *Result of Case Study 2 obtained using EHSI*

pipe	pipe diameter(mm)	pipe cross-section area(m^2)	velocity of flow (m/s)	cost of network($Naira$)
1	95.0	0.2017	0.1332	328,000
2	94.5	0.2187	0.2157	260,050
3	95.0	0.2215	0.1185	219,000
4	95.0	0.2013	0.1000	219,000
5	95.0	0.2000	0.1000	284,700
6	93.5	2.0000	0.5000	265,190
7	95.0	0.2000	0.1719	262,800
8	91.0	2.0000	0.1000	311,510
9	95.0	2.0000	0.5000	240,900
10	93.5	1.9077	0.5000	318,230
11	95.0	2.0000	0.5000	328,500
12	95.0	2.0000	0.5000	284,700
13	95.0	2.0000	0.5000	219,000
Total				3,542,100

Case study 3

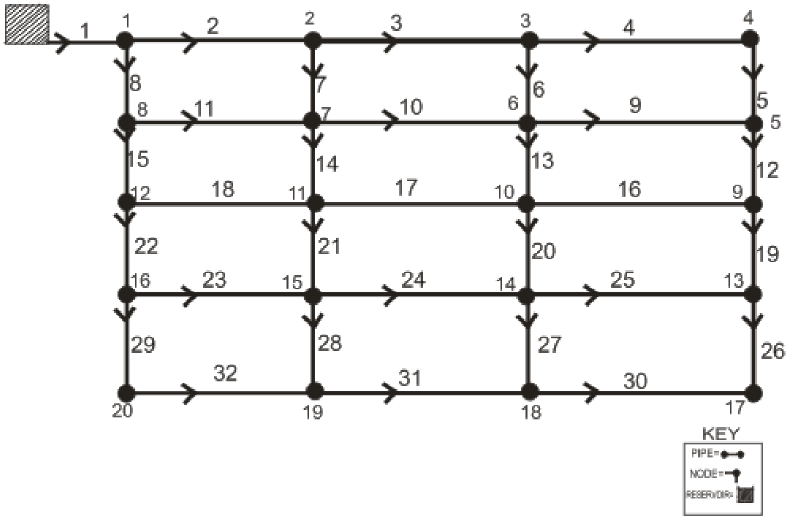

Figure 4: Pipe Network Layout For Ipata Oloje, Ilorin.

Case study 3 is the network layout for Yalu street, Ipata Oloje, Ilorin, which comprises thirty one(32) pipes and twenty(20) nodes as shown figure 3.3. The head losses were calculated using Hazen-Williams equation and every diameter has a dimensionless roughness coefficient C equal to 130 with the data given in Table 3.9

Table 3.9: Geometric data of network layout for Ipata Oloje, Ilorin

pipe	pipe length(m)	pipe diameter(m)	flow along the pipe (l/s)	cost of network($Naira$)
1	100	200	0.182	1,221,000
2	155	100	0.283	161,210
3	120	100	0.219	599,185
4	100	200	0.182	910,166
5	200	150	0.365	17,27,000
6	100	100	0.182	984,211
7	150	145	0.273	1,513,511
8	100	100	0.182	892,111
9	100	120	0.182	954,022
10	150	200	0.273	500,491
11	100	100	0.182	570,085
12	150	100	0.273	172,8000
13	100	200	0.182	967,600
14	150	155	0.273	1,481,800
15	150	200	0.273	1,329,416
16	100	100	0.182	1,000,222
17	130	150	0.237	531,500
18	140	155	0.255	450,211
19	150	200	0.273	1,705,000
20	100	123	0.182	1,000,100
21	120	170	0.219	1,310,000
22	140	161	0.255	1,500,000
23	155	122	0.283	1,495,600
24	100	145	0.182	1,000,100
25	150	122	0.182	1,600,000
26	100	190	0.182	900,000
27	150	123	0.273	1,511,000
28	155	143	0.283	74,5110
29	100	125	0.182	928,120
30	140	160	0.255	1,311,111
31	150	200	0.182	1,611,200
32	100	122	0.182	999,100
Total				35,138,182

* Source:Kwara State Water Corporation

Table 3.10: Demand at the nodes of case study 3

node	node demand (l/s)	node	node demand (l/s)
1	0.17	11	0.16
2	0.21	12	0.25
3	0.27	13	0.36
4	0.18	14	0.14
5	0.25	15	0.22
6	0.28	16	0.35
7	0.26	17	0.24
8	0.31	18	0.33
9	0.35	19	0.45
10	0.22	20	0.31

The minimum pressure generated after the simulation by Epanet is 4.71

3.3. Solution to case study 3

After the implementation of case study 1 using the designed model and solved with PSO and EHSI the results in Table 3.11 and Table 3.12 below was obtained.

Table 3.11: Result of Case Study 3 obtained using PSO

pipe	pipe diameter(mm)	pipe cross-section area(m^2)	velocity of flow (m/s)	cost of network($Naira$)
1	95	0.2000	0.1000	219,00O
2	95	2.0000	0.1000	339,450
3	95	0.2000	0.1000	262,800
4	95	2.0000	0.1000	219,000
5	95	0.2000	0.1000	438,010
6	95	1.973	0.1000	219,000
7	95	0.4261	0.1000	328,500
8	95	0.2000	0.1000	219,000
9	95	0.2000	0.1000	219,000
10	95	2.0000	0.1000	328,500
11	95	2.0000	0.1000	219,000
12	95	0.2000	0.1000	328,500
13	95	0.2000	0.1000	219,000
14	95	0.2000	0.1000	328,500
15	95	2.0000	0.1000	328,500
16	95	2.0000	0.1000	219,000
17	95	2.0000	0.1000	135,590
18	200	0.2000	0.1000	135,590
19	95	2.0000	0.1000	328,500
20	200	2.0000	0.1000	968,480
21	95	0.2126	0.1000	262,800
22	95	0.2000	0.1000	306,600
23	95	0.2000	0.1000	339,450
24	95	2.0000	0.1000	219,000
25	95	0.2000	0.1000	328,500
26	95	0.2000	0.1000	219,000
27	95	0.2000	0.1000	328,500
28	95	0.2000	0.1000	339,450
29	200	2.0000	0.1000	968,480
30	95	0.2000	0.1000	306,600
31	200	2.0000	0.1000	1,452,700
32	200	2.0000	0.1000	968,480
Total				12,928,000

Table 3.12: Result of Case Study 3 obtained using EHSI

pipe	pipe diameter(mm)	pipe cross-section area(m^2)	velocity of flow (m/s)	cost of network($Naira$)
1	95.0000	0.2024	0.5000	219,000
2	95.0000	0.2000	0.1449	339,450
3	95.0000	0.2000	0.1000	262,800
4	95.0000	2.0000	0.5000	219,000
5	95.0266	0.2132	0.1000	438,250
6	95.1605	2.0000	0.5000	219,740
7	95.0526	1.9978	0.5000	328,870
8	95.0000	0.2172	0.1684	219,000
9	95.0189	1.9998	0.5000	219,090
10	95.0000	2.0000	0.5000	328,500
11	95.0000	2.0000	0.5000	219,000
12	95.0000	0.2245	0.1000	328,500
13	95.0000	0.2011	0.5000	219,000
14	95.0582	0.2000	0.5000	328,910
15	95.0070	2.0000	0.5000	328,550
16	95.0280	0.2756	0.4316	219,130
17	95.0000	2.0000	0.5000	284,910
18	95.0350	0.2000	0.5000	307,020
19	95.0000	2.0000	0.5000	328,500
20	95.0639	2.0000	0.5000	219,300
21	95.0000	0.5922	0.5000	262,800
22	95.0000	0.2206	0.1000	306,600
23	95.0277	0.2542	0.1000	339,650
24	95.0000	1.9998	0.1443	219,000
25	95.0704	0.2173	0.04994	328,990
26	95.0676	0.2000	0.1000	219,310
27	95.0804	0.1278	0.5000	328,500
28	95.0000	0.2000	0.5000	219,000
29	95.0000	0.2000	0.5000	968,480
30	95.1025	2.0000	0.5000	307,260
31	95.0167	2.0000	0.1159	328,620
32	95.1138	0.2085	0.1117	219,530
Total				9,635,700

Table 4.1:Total Cost of Network Obtained Using PSO, EHSI and Traditional Method

	PSO	EHSI	Traditional Method
Case Study	$C_T(Naira)$	$C_T(Naira)$	$C_T(Naira)$
1	1,099,700	1,080,300	3,071,900
2	3,591,600	3,542,100	11,057,605
3	12,928,000	9,635,700	35,138,182

4. DISCUSSION OF FINDINGS

In this paper three case studies of water distribution network in Ilorin were considered and they were solved by PSO and EHSI algorithm using MATLAB R2010a (7.10.499) run on the PC Intel(R) samsung, a 32 bit Os Laptop windows 7 operating system.

Considering the total cost of network in Table 3.1, 3.3, 3.4, 3.5, 3.7, 3.8, 3.9, 3.11, 3.12 and 4.1, it can be observed that applying the new model and solving PSO and EHSI reduce the total cost of water distribution network. For example in case study 1 for traditional method the total cost of network is N3,071,900, also for PSO is N1,099,700 and for EHSI is N1,080,300. Also in case study 2 for traditional method the total cost of network is N11,057,605 also for PSO is N3,591,600 and for EHSI is N3,542,100 and in case study 3 for traditional method the total cost of network is N35,138,182 also for PSO is N12,928,000 and for EHSI is N9,635,700.

Results also shown in Tables 3.3, 3.4, 3.7, 3.8, 3.11, 3.12, and 4.1 indicate that EHSI performs better than PSO algorithm.

It is therefore recommended that EHSI should be be used in solving water distribution network models.

5. CONCLUSION

The exploration into water distribution network optimization using PSO and EHSI algorithms has yielded significant insights. Across three detailed case studies conducted in Ilorin, it was evident that these algorithms offer substantial reductions in the total cost of the network when compared to traditional methods. Analyzing the total costs across various scenarios revealed consistent trends. For example, in Case Study 1, the traditional method resulted in a total cost of N3,071,900, whereas PSO and EHSI achieved markedly lower costs of N1,099,700 and N1,080,300 respectively. Similar observations were made in Case Studies 2 and 3, reinforcing the efficacy of these optimization techniques. Furthermore, a comparative analysis indicated that EHSI consistently outperformed PSO in terms of performance, as evidenced by the results. Based on these findings, it is strongly recommended that EHSI be adopted as the preferred method for solving water distribution network models. Its demonstrated ability to significantly reduce total costs highlights its potential to optimize resource allo cation and improve overall efficiency in water distribution systems. This conclusion underscores the importance of embracing advanced optimization algorithms for addressing real-world challenges in water management effectively.

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