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Urban Drainage Network Structure Optimization Using Emperor Penguin Optimization Algorithm

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Abstract:

Urban drainage systems are an essential component of urban infrastructure that plays a critical role in managing stormwater and preventing flooding in urban areas. With the changing climate and urbanization, the challenges faced by urban drainage systems are becoming increasingly complex. Additionally, aging infrastructure further exacerbates the problem, creating anurban sewage line that must be made more resilient. Redundancy is just a fundamental characteristic of such a robust urban drainage network. Redundancy in urban drainage systems can help to ensure that the system continues to function during extreme weather events or emergencies, reducing the likelihood of flooding and damage. However, the exact locations where redundancy should be increased and its contribution to resilience are not well understood. In recent years, several studies have focused on developing frameworks for optimising urban drainage structures which account pipeline redundancy.One similar research presented a paradigm for constructing the ideal network layout for urban drainage infrastructure, which considers pipeline redundancy under consideration. The original architecture and structure of the urban drainage network was developed using emperor penguin optimizer algorithms and graph theory in the research. Complicated system modelling was done to find extra water pathways or redundancy which might well be implemented to boost resistance. The suggested approach has been utilised to the test region in Dongying City, Shandong Province, China, and its findings revealed even under rainfall above the design specification, the entire overflow capacity of such urban drainage network including pipeline redundancy significantly decreased about 20-30%, compared to the network without pipeline redundancies. The interest in creating optimization algorithms had also increased recently that can be used to design and manage urban infrastructure systems. One such algorithm is the Emperor Penguin Optimization (EPO) algorithm. EPO was a recently developed swarm-based optimization An algorithm which simulates Emperor penguins behaviour in their search for food in Antarctica.

The algorithm has shown promising results in solving complex optimization problems in different fields, including engineering, computer science, and management. The EPO algorithm's key features include an emperor search strategy, local search, and randomization, enabling that to efficiently and successfully examine the search process. The algorithm's emperor penguin search strategy enables it to dynamically adjust the search parameters based on the problem's characteristics and progress. The local search feature allows it to escape local optima and explore the search space further. Finally, the randomization feature adds stochasticity to the search process, helping to ensure that the algorithm can avoid getting stuck in a sub-optimal solution. In this article, we aim to explore the potential of EPO as a tool for optimizing Urban drainage solutions which take into account pipeline redundancy. We will start by reviewing the existing Literature upon that optimization in urban drainage facilities, particularly the application of particle swarm optimization, genetic algorithms, and ant colony enhancement. The EPO algorithm will next be described in full including its working principle, key features, and the steps involved in applying it to an optimization problem. Finally, we will present a case study that applies the EPO technique was developed to optimise the network model of such an urban drainage infrastructure taking into account pipeline redundancies, and compare the results with other optimization algorithms. Through this, we aim to demonstrate the potential of EPO as a powerful tool for designing and managing urban infrastructure systems, particularly for enhancing the resilience of urban drainage systems. The study will provide valuable insights into the optimal design of urban drainage technologies which take into account pipeline redundancy, helping policymakers and urban planners make informed decisions about improvingthe adaptability of urban drainage networks. The findings can contribute to the development of sustainable and resilient urban infrastructure systems, which are essential for ensuring the well-being and prosperity of urban residents.

Keywords: Urban Drainage Network, Emperor Penguin Optimization Algorithm, Hydraulic Layout, Storm Water Management Model

1. Introduction

The recommended experimental framework, primarily depicted in Figure 1, consists of three major components. The initial stage is to use a graph theory technique for determine the basic structure of both the urban drainage network. In its second step, an emperor penguin algorithm is employed to obtain the optimal hydraulic design. The third step involves using complex network examination to identify crucial nodes that can increase loop and redundancy, and analyzing the system's resiliency effectiveness. The analysis primarily concentrates upon the above structure’s effectiveness inside the event of a functional breakdown, employing two specified metrics: mean flood duration (MFD) and total overflow volume (TOV) [14,15]. Whenever the outflow discharge surpasses the capacity of drainage, the amount of rainwater which runs through the drainage system has been referred to as TOV, while MFD refers to the average duration of the flood.

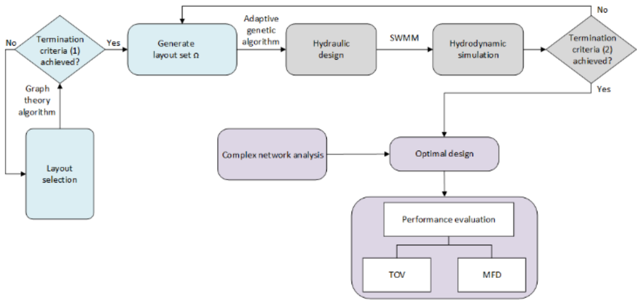

Fig.1. An elevated summary of such proposed research paradigm.

Termination requirements (1): include all subsequence’s; termination condition (2): confirm that all patterns in have been hydraulically constructed. SWMM stands for storm water management system [28]; TOV refers for total overflowing flow, and MFD refers for median flood timeframe.

A. METHODOLOGY AND DATASETS

The portion explains the approaches utilized before implementing those towards a research location in "Dongying, Shandong Province, China", like pattern choosing, hydraulic layout, and complicated network evaluation.

B. METHODOLOGY

The infrastructure of urban drainage systems primarily based upon a framework of design choosing and hydraulic planning, using complex network evaluation used further to enhance the network model.

C. SELECTION OF LAYOUT

Choosing a structure comprises deciding the spot as well as amount of water pipes, selecting suitable pipelines, and determining the pattern of flow of water. Graph theory techniques [17,25]. Aare commonly used to assist with layout selection. A network was made up of connections and vertices, where vertices also edges represent manholes and pipes, respectively. The starting graph contains every possible pipeline, as well as the loop-by-loop chopping approach is used to gradually remove edges from the undirected base graph to build a workable tree architecture [6,28]. Figure 2 depicts the process utilised in this study for layout selection, which involves the following steps: (1) creating the base graph G (V, E) and recognising every loops inside the main graph; (2) selecting a loop and eliminating a border from the loop while maintaining connectivity of the remaining edges; (3) checking for any remaining loops in the graph and repeating step (2); (4) obtaining every subgraphs which won't comprise any loops (Fig. 2).

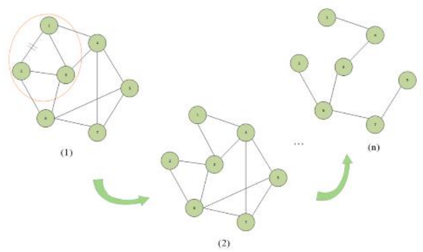

Fig 2. Selection of Layout

D. HYDRAULIC DESIGNING

The hydraulic layout was generally utilized to determine the size and slopes in order to reduce the requirement of filling stations and pressurised pipelines.

1. OBJECTIVE FUNCTION

Difficulty on optimising the urban drainage network might be described like follows:

$$Minimize\ F = \sum_{i=1}^{N} C_i(D_i, H_i) \times L_i \qquad (1)$$

wherein F indicates the optimization technique, N signifies the overall numbers of pipelines$i$: D_i represent the diameter, H_i is the submerged depths, and L_i is the pipeline lengths.

2. DESIGN CONSTRAINTS

The hydraulic layout of such urban drainage infrastructure should comply towards the appropriate flow velocity, pipe diameter, and buried depths restrictions:

$$D_{min} \le D \le D_{max} \quad (2)$$

$$D_{down} \ge D_{up} \quad (3)$$

$$D \in D_s = \{D_1, D_2, D_3, \ldots, D_Z\} \quad (4)$$

$$v_{min} \le v \le v_{max} \quad (5)$$

$$dh_{min} \le H \le dh_{max} \quad (6)$$

In which D_{min} represents the minimal pipeline diameter, D_{max} defines the maximal pipeline diameter, D represents the flowing pipeline diameter, D_{down} denotes the downstream pipeline diameter, and D_{up} represents the upstream pipeline diameter v denotes the flow rates, v_{min} seems to be the minimum flow speed, v_{max} seems to be the maximum flowing velocity, dh_{min} seems to be the buried depths, H denotes the depth buried, also dh_{max} represents its greatest depth buried.

3. EMPEROR PENGUIN OPTIMIZER

The emperor penguin optimizer (EPO) method was indeed the unique meta-heuristic technique invented by Dhiman around 2018 that is motivated from emperor penguin huddling habits. Emperor penguins snuggle together just to stay warm during the hard Antarctic winters, when temperatures might drop below dangerously lower degrees. The huddling activity of emperor penguins was distinctive and also is affected by a variety of elements such like distance, temperature, and efficient movements inside the cuddle. The EPO methodology was founded on above and other parameters, with the observer and update equations emulating temperature and distance, respectively. This algorithm has been tested on several optimization problems and has shown to be effective. The basic goal of emperor penguin huddling is just to optimise the environmental temperatures inside the cuddle and preserve energy. The temperature T was proportional towards the huddle polygon R circle, which means that as the radius of the huddle increases, the temperature also increases.

$$T = \begin{cases} 0. \ if \ R > 1 \\ 1. \ if \ R < 1 \end{cases}, \quad (7)$$

$T_0$is a temperature profile It's in charge of the drilling and extraction procedures. It really is calculated as specified:

$$T_0 = T - \frac{MI}{CI - MI}, \quad (8)$$

where T_0 represents the temperature distributions surrounding the cluster, MI represents the maximal quantity of repetitions, and represents the current iteration CI .

The separation among the best-determined optimum approach and the emperor penguin Whenever the huddle boundary was formed, D gets calculated.

$$D = S(A).P_{ep}(x) - C.P(x), \quad (9)$$

Where,

$S(A)$ denotes emperor penguin social forces.

$P(x)$ signifies the emperor penguin's current position vector.

A, C denotes neighbour anti-collision factors.

$P_{ep}(x)$ signifies the vector of most optimum solutions discovered.

A and C are in charge of fine-tuning the distance D, and they may be computed using the following equations:

$$C = rand_1, \quad (10)$$

$$A = M \times (T_0 + P_g(ac)) \times rand_2 - T_0, \quad (11)$$

$$P_g(ac) = P_{ep}(x) - P(x), \quad (12)$$

Where, M is the mobility parameter that maintains a collision distance between search agents' avoidance. The polygon grid accuracy is defined as $P_g(ac)$ by comparing the difference between emperor and penguins.

The calculation of S(A), which directs the optimal search agent towards the best direction, can be determined using Equation (13). On the other hand, Equation (14) is used to update the position of the search agent.

$$S(A) = \left(\sqrt{f.e^{-x/l} - e^{-x}}\right)^2, \quad (13)$$

$$P(x+1) = P_{ep}(x) - A \times D, \quad (14)$$

where f and l are parameters that influence exploration and exploitation. P(x+1) indicates the emperor penguin's next updated position.

Table 1 shows the proposed values for the parameters utilised in the EPO algorithm, according to [1]. Figure 3 depicts the "flow chart of the EPO algorithm", whereas following are the major processes in executing EPO:

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Table 1: Parameter settings for the emperor penguin optimizer (EPO) algorithm [1].

<table>
<tr><th>Parameter</th><th>M</th><th>Rand 1</th><th>Rand 2</th><th>f</th><th>l</th></tr>
<tr><td>Minimum value</td><td rowspan="2">Set to 2</td><td>0</td><td>0</td><td>2</td><td>1.5</td></tr>
<tr><td>Maximum value</td><td>1</td><td>1</td><td>3</td><td>2</td></tr>
</table>

Step 1: Set the starting variables for rand1, rand2, R, T, T0, A, C, S(A), M, f, and l.

Step 2:produce initial values for important parameters P(x) and compute their fitness values (objective function).

Step 3:determine the best initial optimum solution based on the computed fitness.

Step 4: Begin the first iteration by computing the new T0, S(A), Pg(ac), and A values.

Step 5: Determine the amount of D and apply it to the best option. Pep(x) is used to compute the new and updated solutionsP(x+1).

Step 6:choose the greatest new ideal solution and save it in Pep (x). Moreover, save the appropriate best fitness.

Step 7: If the iterations have not ended, return to Step 4 and repeat until the maximum number of iterations has been achieved.

Step 8: Examine the fitness array to discover the best fitness and present the answer.

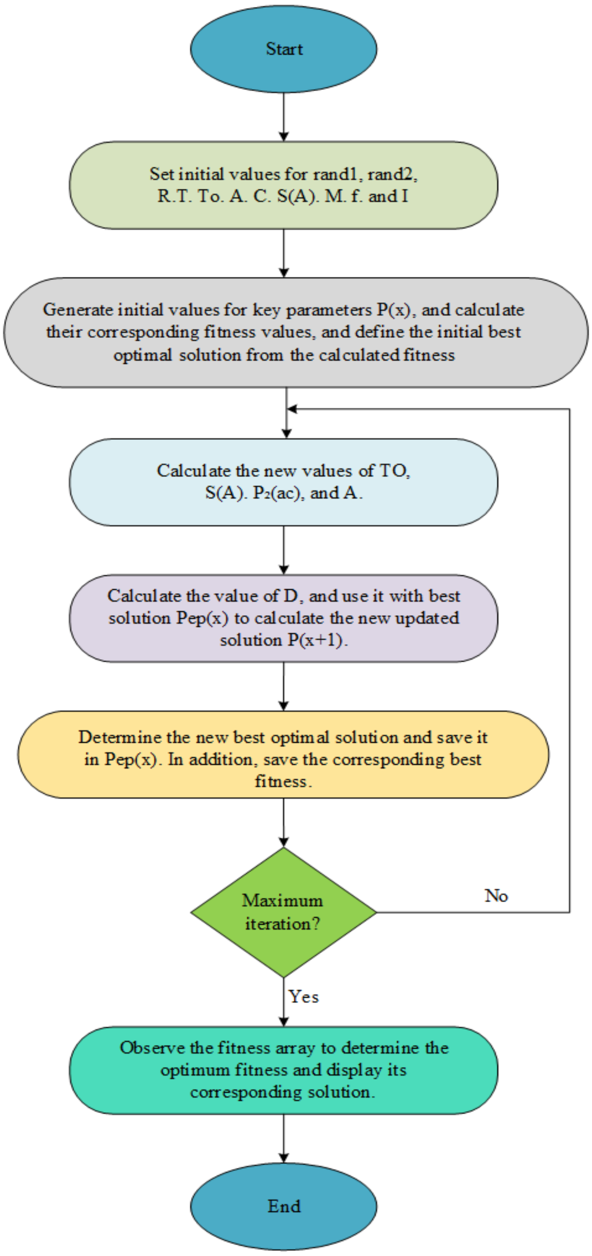

Figure 3. Flow chart of EPO

A. Evaluation of Complex Network

Acomplex two-layer networking evaluation was created, comprising a global networking examination conducted to every nodes as well as a local system evaluation performed to every node independently (Fig. 4).

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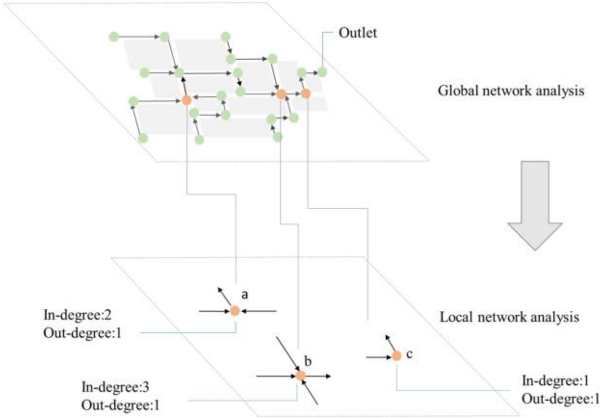

Fig. 4 The connection among global networking evaluation and local networks evaluation

B. GLOBAL NETWORK ANALYSIS

The application of global network evaluation can be useful in identifying crucial nodes in urban drainage systems. closeness centrality, like as betweenness centrality and Centrality measures [2,5] are commonly used to evaluate the role of specific nodes in the network and their impact on the overall system. For large water distribution systems, the demand can be estimated using betweenness centrality **[22]**. In sewage systems, the edge betweenness centrality [8] can be adjusted to indicate what regularly an edge appears inside the quickest route among the supply vertices as well as the output. The research makes specific changes towards the centrality measurements. Betweenness centrality was characterised by the frequency that a particular node emerges upon that network's smallest route. Closeness centrality, on the opposite hand, was determined as such average distances from a nodes towards the exit. These modifications can help to further analyze and identify the “critical nodes inside the urban drainage system.

$$C_B(v) = \sum_{s \neq t \neq v \in V} \frac{\sigma_{st}(v)}{\sigma_{st}} \quad (15)$$

$$C_c(v) = \frac{1}{\sum_{t \in G} d_G(v,t)} \quad (16)$$

$$I = w_1 \times C_B(v) + w_2 \times C_c(v) \quad (17)$$

where $C_B(v)$ is the centrality betweenness; s, v, t are nodes; V denotes the node set; $\sigma_{st}(v)$ denotes the number of shortest pathways from s to t through v; σ_{st} denotes the number of shortest paths from s to t; $C_c(v)$ is the centrality of proximity; G is the graph; $d_G(v,t)$ is the shortest path linking nodes v and t in G; I is node value; and $w_1$and $w_2$are weights calculated by the Analytic Hierarchy Process. $w_1$is 0.2 and ww_2 is 0.8 in this investigation”. Analytic Hierarchy Process analysis was performed Zhang [30].

4. EVALUATION OF LOCAL NETWORK

Local network evaluation, that comprises degree (d), indegree (d_{in}), out-degree (d_{out}), as well as the maximum degree (d_m), was a concentrated Evaluation of nodes having greater scores resulting on global system evaluation. The degree indicates how numerous edges were connected toward a node.

In-degree represents how all those sides approach the cluster; out-degree represents how often edges leave the cluster; and maximal degree represents the maximal amount of edgesthat may connect to the node:

$$d = d_{in} + d_{out} \tag{18}$$

If d = dm, redundancies may be raised; otherwise, redundancy can indeed be enhancedif d <d_m,. Consider node c in Fig. 4, which has a greatest severity of 3; the present in-degree is 1; the existing out-degree was 1; there seems to be opportunity for enhance redundancies. Node b has no space for redundancy since it's able to have a greatest value of 4, whereas the in-degree and out-degrees currently are 3 and 1, correspondingly.

C. Datasets and the Study Area

The study location was 8.916 km2 in size and also is positioned inside the eastern portion of Dongying City Centre, Shandong Province, China (Fig. 5). [20].

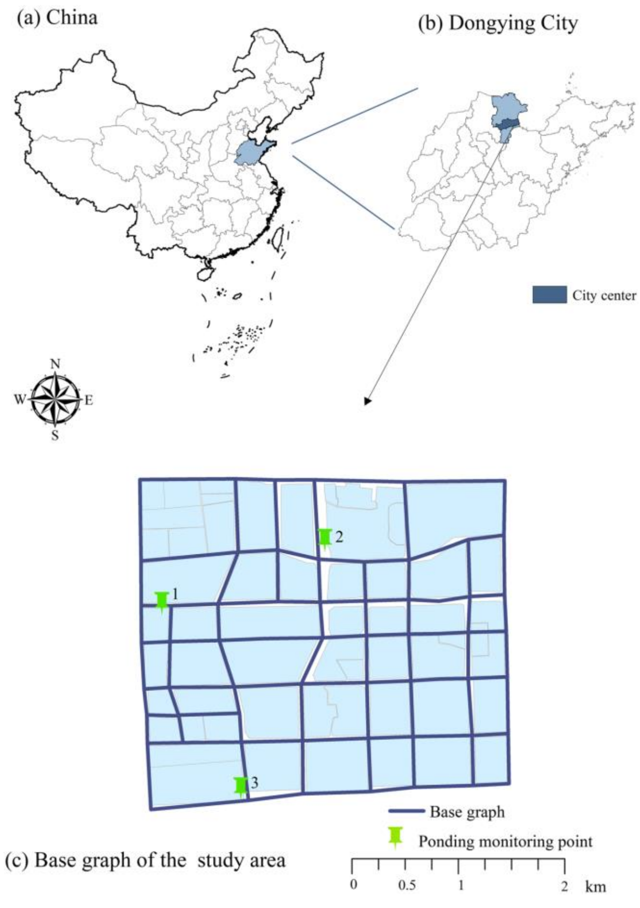

Fig. 5 Location of the study area in Dongying City, Shandong Province, China. **(a)** China; **(b)**Dongying City; **(c)** Study Area Basic Graph

For hydraulic analysis, [21]; the Storm Water Management Model (SWMM) were utilized. Employing a digital method of the elevation information and the current condition, the characteristics of the sub catchment as well as the basic stormwater technology were obtained [3,11]. The experimental area has a strong elevation inside the south as well as a lower elevation with in north.

The degree of impermeable covering was 90.9%. Researchers utilized elevation data with such a 30 m 30 m resolution and industrial usage information with just an accuracy of 10 m 10 m. (Fig. 6).

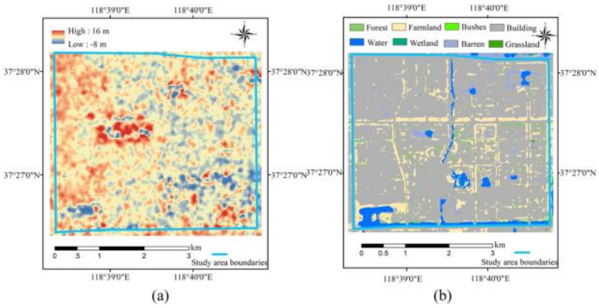

Fig. 6 An illustration of the research field. **(a)** Elevation of the ground; **(b)** Land Usage

The entire extent of the primary drainage pipeline was 25,142 m, as well as the pipeline thickness was 2.82 km/km2. The tunnel's dia ranges after 300 through up to a 2000 mm.The researching location features ponding point monitoring equipment also a neighbouring rain gauge station. Rain-gauge station noted rainfall data from August 18 to August 20, 2018, and the flooding depth data from the three waterlogging stations were utilised to fine-tune the settings(Fig. 7a).

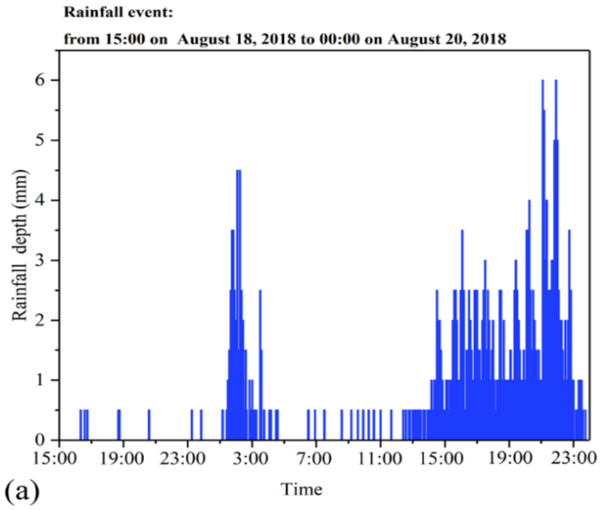

Figure 7 depicts the rainfall data utilised in the research. **(a)** A rainfall event was utilised to calibrate the system;

Because all errors are within 10%, the model is acceptable as given in the Table 2.

Table 2 The three waterlogging locations' flooding depths

point of Waterlogging	value Observed (m)	value Simulated (m)	$R_e = \frac{\lvert V_{sim} - V_{obs} \rvert}{V_{obs}} \times 100\%$
1	0.255	0.261	2.4%
2	0.238	0.217	8.8%
3	0.200	0.219	9.5%

Where the Table 3 displays SWMM's final calibration parameter values.

Table 3 Characteristics for the storm water management framework that have been calibrated

Parameters	Explanation	rateof Calibration
N-imperv	Manning's n for the overland flowing across the sub catchment's impervious part	0.015
N-perv	Manning's n governing overland flowing across the preceding sub-catchment	0.28
Dstore-imperv (mm)	Depth for depressed storing upon that sub catchment's impermeable section	1
Dstore-perv (mm)	Depression storage depth upon this previous segment of sub catch	6
Maxrate (mm h-1)	Highest Horton curve infiltrating speed	51
Minrate (mm h-1)	Horton curve minimum infiltration capacity	3.3

The verification findings demonstrate that its coefficient $R_e$was larger as 0.9, suggesting that its model's reliability and correctness meet requirements (Table 1). The measured readings of its SWMM characteristics are shown in Table 2. Street systems as well as urban water systems have a substantial correlation—around 80% of total sewage networks connect with 50% of roadway networks [13,29]. The arrangement of buildings and roadways in the research area is used to divide sub catchments. To determine the flow direction, Analyses of space are conducted upon that digital concept of elevation. Drainage pipes in high-traffic locations have a design return period of 3-5 years. Around Dongying City, where the research location was situated northern residential sector, which is a heavily populated residential neighbourhood. For safety reasons, the 5-year returning period regarding designing pipelines was established.

The hydraulic evaluation [7,18] in its urban draining infrastructure utilizes rainfall between 10- and 20-year returning intervals (see Fig. 7b). The Rainfall volumes are 80.7 mm and 92.3 mm for 10- and 20-yearsreturning intervals, correspondingly. The rainfall structure were depicted in to Fig. 7b using Dongying City's rainstorm intensity calculation [4].

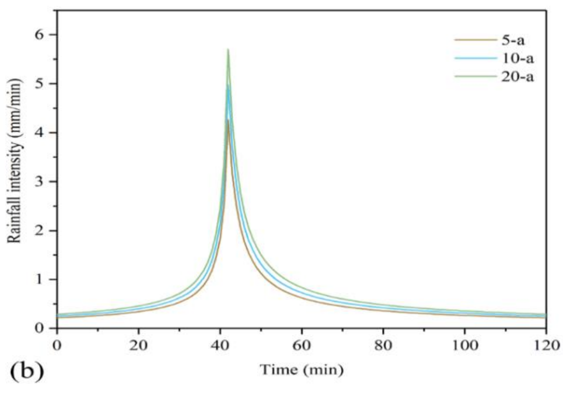

Fig. 7 The research made utilization of rainfall data. **(b)** Create a storm with varied return times (5, 10, and 20 years): 2-h hyetograph layout

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5. Results

Initially, the methodology and datasets presented in Section 4.2 are employed to acquire the configuration of the nearby drainage system. Next, its hydraulic effectiveness relating to the drainage network is evaluated both prior to and following optimization. Finally, the performance of the system is scrutinized with and without redundancy.

A. The Design of the Urban Drainage Network

The fundamental diagram comprises a completely interconnected looped structure containing all potential conduits. Subsequently, utilizing the graph theory algorithm (refer to Section 4.2.2.1) and the emperor penguin optimizer (refer to Section 4.2.2.2), the preliminary optimized design is obtained, which is demonstrated in Figure 8b. The optimized network's overall length measures 23,527 meters, with a solitary drainage outlet. The system's pipeline seems to have a maximal dia of about 2000 mm as well as a minimal dia of about 300 mm. The pits are sunk to a depth of at least of 1.0 m and then a maximal depth of about 6.0 m. The layout of any urban draining infrastructure prior to improvement can be observed inside Figure 8a.

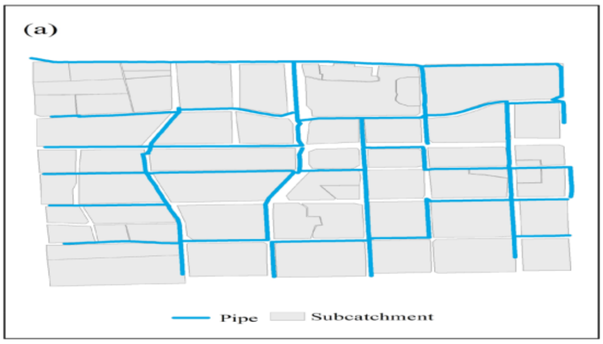

Fig. 8 Dongying Town's urban draining system. **(a)** Pre optimization of the urban drainage system

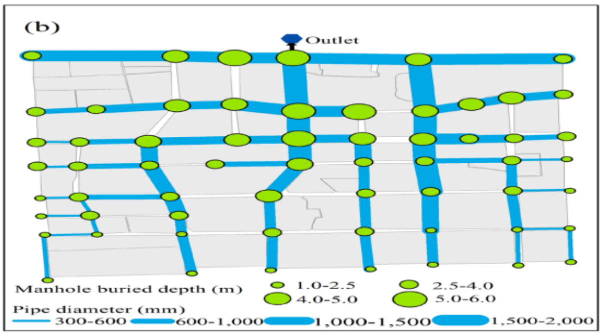

Fig. 8 Urban drainage system of Dongying City centre. **(b)** early optimization of the urban drainage system

B. Evaluation of Hydraulic Performance

Under the 10- and 20-year rainfall conditions, an examination of such hydraulic efficiency of both the upgraded urban drainage structure vs the main drainage channels within the experimental region demonstrates that perhaps the optimised network decreases overall overflowing volumes through 65.7% and 59.6%, correspondingly. The enhanced drainage system outperforms the old system in terms of mean flood duration (MFD) in the Table 4.

Table 4 The actual urban drainage systems and proposed network's effectiveness

Index	PeriodofReturn (year)	Main Drainage system	Optimized Drainage system
Total overflow volume (1000 m3)	10	53.82	18.44
	20	64.90	26.20
Mean flood duration/maximum flood duration (hours)	10	0.80/5.78	0.64/4.17
	20	0.93/6.35	0.74/5.14

The surcharge ratio on the pipelines considerably higher inside the 20-year rainfall situation compared to the 10-year rainy situation (Fig. 9).

Fig. 9 Surcharged pipeline transmission. The percentage of a distance of a surcharged pipeline towards the overall length of the pipe is known as the pipeline surcharge rate.

The majority of its two systems surcharged pipes have been delivered down flowing water. That really was due to the concept that pipelines get surcharged whenever the flow of water is focused downstream [12,24]. and discharge throughout pipeline rises. In order to enhance redundancy [16,27],

also the lower the draining capacity upon that pipelines downstream, it's therefore reasonable to think about adding more pipelines downstream[19].

C. Optimization and Redundancy

Gephi is indeed a tool used to show information and to carry out sophisticated networking analyses upon that urban drainage structure [2]. Gephi is really a network simulation and graphics tool that was open-sourced and free to use1 The shading of colour on the nodes symbolises its centrality betweenness, whereas the width of its nodes specifies the centrality and proximity(Figure 10).

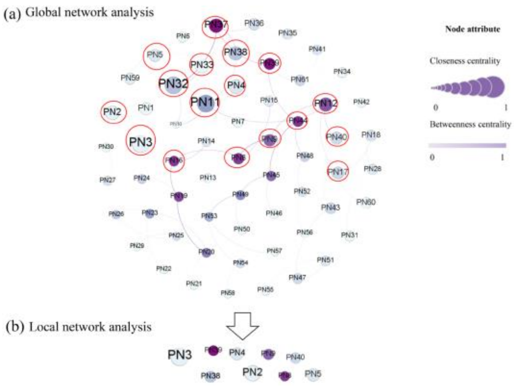

Fig. 10 Results of complex network evaluation (node attribute value visualization)

By performing a “global network analysis’, nodes with higher index values are identified. In order to make comparisons more manageable, these values are normalized, and the resulting index values for each node are displayed in Table 5.

Table 5 Findings of complex network analysis (index values of nodes)

Node	**Closeness centrality**	**Betweenness centrality**	**Value**	**Node**	**Closeness centrality**	**Betweenness centrality**	**Value**
PNII	1.00	0.44	0.88	PN15	0.33	0.07	0.28
PN32	1.00	0.28	0.86	PN28	0.33	0.07	0.28
PN3	1.00	0.03	0.81	PN48	0.29	0.18	0.27
PN37	0.66	1.00	0.73	PN6	0.33	0.00	0.27
PN12	0.66	0.74	0.68	PN23	0.22	0.42	0.26
PN38	0.67	0.25	0.59	PN41	0.29	0.09	0.25
PN39	0.44	0.99	0.56	PN53	0.22	0.36	0.25
PN4	0.67	0.08	0.55	PN14	0.29	0.08	0.24
PN2	0.67	0.03	0.54	PN51	0.29	0.08	0.24
PN9	0.50	0.66	0.53	PN24	0.25	0.18	0.24
PN33	0.67	0.00	0.53	PN34	0.29	0.00	0.23
PN8	0.40	0.84	0.49	PN7	0.29	0.00	0.23
PN44	0.35	0.87	0.46	PN31	0.29	0.00	0.23
PN16	0.33	0.86	0.44	PN52	0.25	0.11	0.22
PN40	0.50	0.16	0.43	PN26	0.20	0.24	0.21
PN17	0.50	0.16	0.43	PN13	0.25	0.00	0.20
PN5	0.50	0.08	0.42	PN55	0.25	0.00	0.20
PN1	0.50	0.00	0.40	PN46	0.25	0.00	0.20
PN36	0.45	0.13	0.39	PN42	0.25	0.00	0.20
PN19	0.29	0.79	0.39	PN27	0.22	0.11	0.20
PN45	0.29	0.64	0.36	PN54	0.20	0.13	0.18
PN43	0.40	0.16	0.35	PN21	0.22	0.00	0.18
PN18	0.40	0.11	0.34	PN50	0.22	0.00	0.18
PN59	0.40	0.05	0.33	PN56	0.22	0.00	0.18
PN60	0.40	0.00	0.32	PN25	0.18	0.13	0.17
PN61	0.35	0.16	0.31	PN22	0.20	0.00	0.16
PN20	0.25	0.55	0.31	PN30	0.20	0.00	0.16
PN49	0.25	0.53	0.31	PN57	0.20	0.00	0.16
PN35	0.35	0.08	0.30	PN58	0.18	0.00	0.14
PN47	0.33	0.13	0.29	PN29	0.17	0.00	0.13

The connections featuring the greatest index scores are further subjected to local network evaluation to determine potential pipeline redundancy improvement sites. The inclusion of pipelines having greater and smaller terminal values has been shown in Figures 11a and b, appropriately.

Fig. 11 Structure has been optimised to account for pipeline redundancies. Network **(a)** adds pipes in which the node value was greater; Network **(b)** generates pipelines in which the node values is less. The pipeline node is denoted by PN, while the pipe is denoted by GQ.

The existing drainage platform's network design was improved according to the findings of the complex network evaluation [6,23,10]. The place having the weakest node number was picked to improve redundancies and illustrate the usefulness of a complicated network evaluation technique [9,26]. The features of the implanted pipelines are summarised within Table 6.

Structure	**Pipe**	**Length (m)**	**Diameter (mm)**	**Slope (%)**
(a) Increase loops where the node value is higher	GQ1	713	1000	1.4
	GQ2	682	1500	3.4
	GQ3	542	1000	1.8
	GQ4	419	1000	2.4
	GQ5	387	1200	2.1
	GQ6	502	1200	2.0
(b) Increase loops where the node value is lower	GQ7	596	1000	4.2
	GQ8	654	1200	3.7
	GQ9	445	1000	3.3
	GQ10	639	1000	3.8
	GQ11	555	1200	4.1
	GQ12	428	1000	5.5

Table 6 Parameters of the introduced pipes networks as well as the optimised systems

These values are “31.6% and 20.2% lower, respectively, then the preliminary optimized network. Meanwhile, the TOV of network (b) measures 16,690 m3 and 25,500 m3 under the 10-year and 20-year rainfall scenarios, respectively, demonstrating a reduction of 9.5% and 2.7%” compared to the network. In comparison to the preliminary optimized network, the average and maximum flood duration of network (a) both decreases, with the maximum flood duration demonstrating a more noticeable decrease. The mean and maximum flood duration also decrease in network (b), albeit the reduction is less significant than in network (a). These results indicate that the network that incorporates pipes at higher node values exhibits greater resilience.

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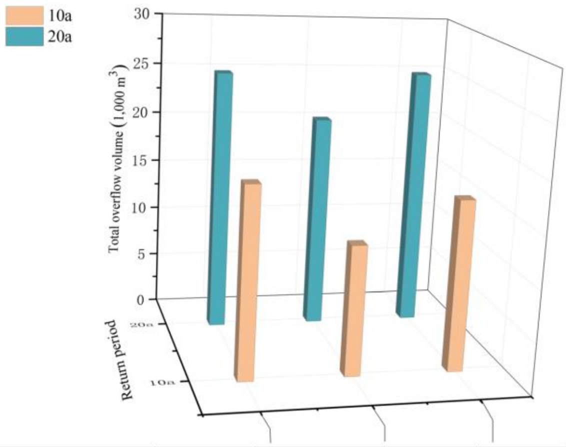

Mean flood duration/maximum flood duration (hours)	Return period	Preliminary optimized network	Network (a)	Network (b)
	10-a	0.64/4.17	0.59/1.80	0.62/3.97
	20-a	0.74/5.14	0.71/2.02	0.73/4.81

Fig. 12 Comparison of drainage effectiveness for 10- and 20-year returning durations among the preliminary optimised

Network (a) adds 3245 m of total length with a pipeline dia of up to 1500 mm. The length of system (b) is increased by 3317 m, and the largest pipeline dia is 1200 mm. In different rainy scenarios, networking (a) and (b) functionality were predicted.

As depicted in Figure 12, the ‘total overflow volume (TOV) of network” (a) during the 10-year and 20-year rainfall scenarios measures 12,610 m3 and 20,910 m3, respectively.

4.5 Conclusion

Urbanization and climate change have made urban flooding a more frequent issue in many places across the world. For the purpose of managing flooding and averting disasters, urban drainage systems must be able to handle significant amounts of precipitation. To be effective, these systems must be carefully planned and designed as they are frequently complicated. A critical problem is optimising the network structure of urban drainage infrastructure to improve effectiveness and resiliency. In urban hydrology, this is a crucial scientific problem. A study crew has proposed a technique to optimising the network model of urban drainage structures which blends the graph theory technique, the complex network, and emperor penguin evolutionary algorithm modelling to tackle this challenge. The network topology of urban drainage systems may be optimised using this technology, which makes it possible to precisely identify where to enhance pipeline redundancies. This technique's early phase involves applying graph theory and emperor penguin algorithms to create the initial optimal hydraulic design and layout. Throughout this method, the network topology is optimised by using graph theory and mperor penguin algorithms once a completely looped structure with all conceivable conduits interconnected has been created. Usually, the optimised network that emerges is a lot more effective than the base network. The second phase involves using complicated network evaluation to locate the network's essential nodes and boosting structural redundancy where node values are greater in order to strengthen the platform's resiliency.The issue of where to enlarge the loop is resolved by using complex network analysis to determine the critical nodes in the drainage network and then pinpoint the position of additional pipes. The case study in an urban setting illustrates how expanding the network's pipeline redundancies might enhance drainage performance. The structure that incorporates redundancies can reduce the total overflow volume (TOV) by 20–30% and the maximum flood duration by 2-3 hours when compared to a structure that does not. The results show that a network with more redundant pipelines is both more successful at reducing floods and has greater potential to increase resilience.

Because of the structure and interaction of edges and nodes, pipe networks in urban drainage systems frequently exhibit a variety of spatial and temporal behaviours. The issue of where to enlarge the loop is resolved by the complicated network analysis employed in this technology, which makes it possible to identify the critical drainage network nodes and then pinpoint the locations of new pipes. The newly created network structure optimization approach presents new potential for enhancing the flexibility of the urban storm water structures and a means to improve pipeline redundancies. The suggested approach may have a number of advantages. To begin with, it makes it possible to precisely pinpoint where to add pipeline redundancies in order to improve the network layout of urban drainage systems. Secondly, it can improve drainage performance and reduce the risk of flooding. Thirdly, it can increase the resilience of urban storm water systems by increasing pipeline redundancies. Finally, it provides a new way to design and plan urban drainage systems that are based on complex network analysis and optimization techniques. However, there are also some limitations and challenges to this method. In order to improve the drainage performance of urban drainage networks, it is first necessary to further explore the cost-effectiveness of expanding redundancy. Second, it is advised that future research use resilience indicators to assess how redundancy affects system reliability. Thirdly, the method needs to be validated through more case studies and comparisons with other optimization methods. In summary, the suggested optimization strategy again for network layout of urban drainage channels does have the capacity to strengthen the resiliency of urban storm water facilities, enhance drainage effectiveness, and lower the danger of floods. It uses the graph theory method, the emperor methodology, and complicated networking evaluation to pinpoint the network's most important nodes and boost pipeline redundancy where node values are greater. Future studies should examine the cost-effectiveness of boosting redundancies and create resiliency indexes to assess how redundancy affects system reliability.

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