Journal of Integrated
SCIENCE & TECHNOLOGY

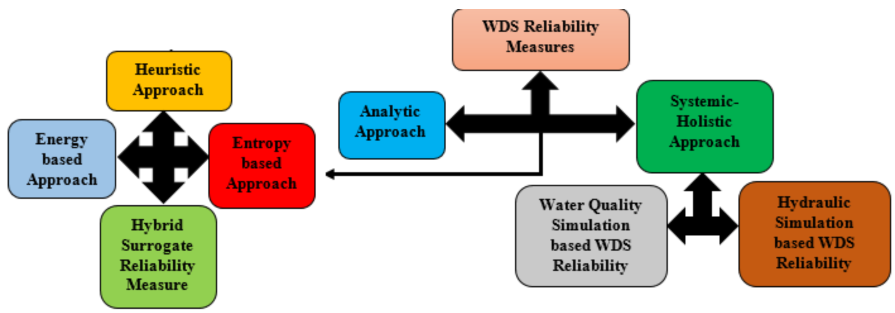
Review of reliability indices of the water distribution system

Suja S Nair[1*], T R Neelakantan[2]

[1]*Department of Civil Engineering, UKF College of Engineering and Technology, Paripally, Kollam, Kerala, 691302. India.*
[2]*Department of Civil Engineering, Kalasalingam Academy of Research and Education, Anand Nagar, Krishnankoil-626126, Tamil Nadu, India.*

Received on: 16-May-2022, Accepted and Published on: 21-July-2022

ABSTRACT



Over the last few years, there has been a growing emphasis on reliability in water dissemination networks. The water supply network's dependability is crucial in today's water delivery system. The capacity of a water distribution network to fulfil requirements with significant pressure under normal and abnormal situations is referred to as system reliability. The development of a system for analyzing and enhancing the reliability of water delivery systems is underway. Enhanced options are offered to increase network dependability, and then an optimization study is used to choose the best upgrade option based on a predetermined goal function. Reliability does not rely on certain criteria. In today's world, computer-aided programs impact the simulation model and the water supply network study. This analysis shows the factors that can be utilized to determine dependability.

Keywords: Water Network, Dependability, Availability, Mechanical Reliability, Hydraulic Reliability, Water Network Assessment

INTRODUCTION

Water delivery networks (WDNs) are intended to offer customers the smallest satisfactory supply level at all times, under varied operating conditions, in terms of workload, supply, and quality of water. WDNs have become increasingly complex, necessitating large investments in construction and maintenance. As a result, there is a strong desire to increase their efficiency by lowering their costs while increasing their benefit. The idea of "system reliability," which estimates marginal capability to meet users' needs, may be used to understand the projected performance of an infrastructure system. The system dependability of a water delivery network (WDN) denotes the steady presentation of supplying necessary water with sufficient service pressure.

Among the most important key metrics for Water distribution systems, "resilience" was defined by Wildavsky[1] as the capacity to adapt to unexpected threats once they have materialized and learn to recover fully. Comfort[2] described resilience as adapting present resources and skills to shifting scenarios and operating environments. Maier et al.[3] presented a first-order estimation technique for water quality services in streams, such as dependability, susceptibility, and resistance, and Bruneau et al.[4] summarised earthquake resilience of an infrastructure system into four R's: robustness, redundancy, resourcefulness, and rapidity. Several studies[5] examined the presentation of various WDNs using basic forms of WDN dependability is determined by hydrological measurements such as average surplus head, minimum surplus head, and supplied demand. Furthermore, Marlim et al.[6] and Markov et al.[7] observed that a WDN's efficiency could be measured by customer satisfaction after splitting and defining the dependability goals of a WDN's user service into societal, financial, hydrological, and water quality. To quantify this, they suggested a serviceability index.

The schematic represtation of Water Distribution System shown in Figure 1. Reliability analysis is essential in designing, operating, and maintaining water distribution systems (WDS) and the Key influential factors affecting WDS reliability results which is shown in figure 2. Many academics have sought to integrate dependability as one of the objectives to be achieved in WDS design without causing the system's cost to increase. Reliability analysis is essential in designing, operating, and maintaining water

*Corresponding Author Ms. Suja S. Nair
UKFCET, Paripally, Kollam, Kerala, 691302. India
Tel: +91-9400775510
Email: hodce@ukfcet.ac.in

Cite as: *J. Integr. Sci. Technol., 2022, 10(2), 120-125.*

 ISSN: 2321-4635 http://pubs.iscience.in/jist

dissemination schemes (WDS). Numerous academics take sought to include dependability as one of the objectives to be optimized in WDS design without causing the system's cost to increase.

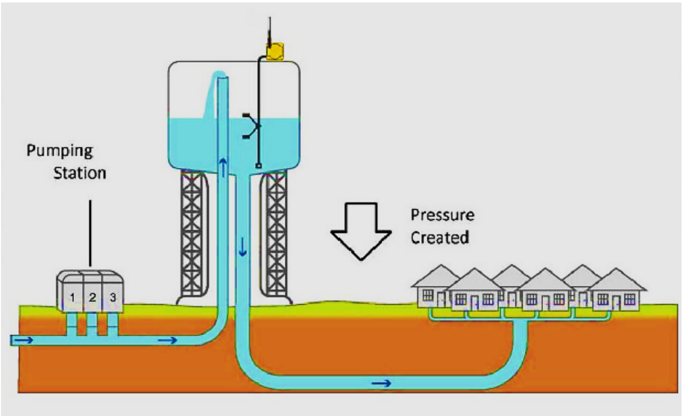


Figure 1: Water Distribution System Model

The basic purpose of a water delivery method is to deliver a continuous water source at the appropriate force at the lowest possible price of scheme structure and process. Water system dependability is an unintended indicator of consumer fulfilment with the quality of water delivery facilities. In the construction of water delivery systems, dependability is often disregarded. The current idea focuses on the functional layout, valve distribution, demand, and pressure requirements, instead of overall performance in the event of a component failure.[8] One of the maximum problematic challenges that academics working on water supply systems confront is the dependability of the distribution network. The lack of a commonly acknowledged metric for network dependability has complicated the real measurement of reliability in these networks. Various scholars have developed a variety of dependability metrics for water supply systems. The difficulty of ensuring reliability is one of the reasons why it has not yet become such a standard design phase.[9-17]

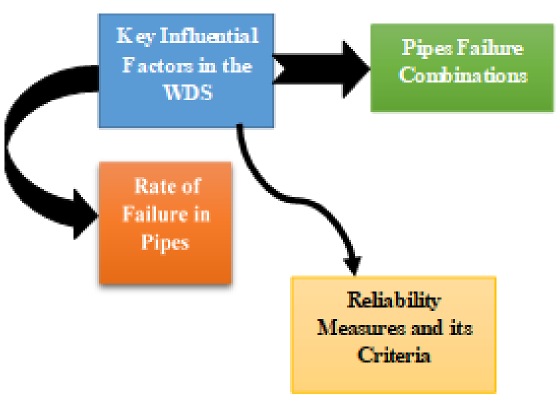


Figure 2: Key influential factors affecting WDS reliability results

Water system construction and layout have prioritized dependability since the early twentieth century. Several of the practical ways in which consistency is addressed in an existing water supply system include having properly trained workers, proper communication, adequate inventory levels of replacement parts and fixtures, rewinding, isolation valves, numerous sustains, backup pumps, storage facilities, backflow prevention, emergency supply storage tanks, telemetry, or Supervisory Control and Data Acquisition (SCADA), and standby power. A water supply system's hydraulic dependability reveals how well it functions. Communication between the pipeline system, transmission handling, transmission pumping, and system appurtenances such as stress minimizing valves, check valves, and other system appliances; specific system component reliability; spatial and temporal variation in demand; and because demand is spatially and temporally distributed.

This study investigates the relationship between representative reliability indices and hydraulic measurements to identify the most appropriate reliability coefficient based on the desired system performance in various scenarios.

LITERATURE SURVEY

Mays[18] describes hydraulic dependability as a system's capacity to provide needed water needs and force under normal and pathological conditions. In contrast, mechanical dependability is defined as system architecture measuring system connectivity under specified failure scenarios. Bao et al.[19] evaluated the nodal and hydraulic method consistencies of water circulation methods while considering imperfections. Monte Carlo simulation is employed in three primary works: generating random values, simulating hydraulic systems, and calculating dependability. As a result, the hydraulic dependabilities of water circulation systems at the node and system levels are determined. The main advantage of this technique is that it can be applied to the study or extension of current methods and the proposal of innovative methods. Awumah et al.[20] presented an entropy dependability rating by establishing water distribution variety in a Water Distribution Network. At the same time, Tanyimboh and Templeman[21] implemented flow entropy into Water Distribution Network research created on Shannon's entropy notion.[22] Raad et al.[23] introduced a new combined reliability coefficient that combined hydraulic and entropic approaches and used performance measurements to compare four distinct reliability indices in a benchmark system. Wagner et al.[24] were the first to establish and apply mechanical and hydraulic dependability ideas to Water Distribution Networks. Prasad et al.[25] described a multi-objective genetic algorithm technique for designing a water dissemination system. The purposes of minimizing system cost and maximizing a dependability metric are explored to get the Pareto-front. A new dependability metric known as network resilience is presented. Todini[26] created the resilience index (RI), which measures the excess and necessary energy in a Water Distribution Network. Jayaram and Srinivasan,[27] on the other hand, developed a modified resilience index (MRI) with different energy content. Later, Liu et al.[28] and Jeong et al.[29] discovered that a topography connection had an impact on network performance reliability and proposed mixed consistency indices, a piping system hydrostatic resilience index (PHRI). A revised resilience index (RRI) that combined hydraulic and topography approaches.

Creaco et al.[30] discovered that the uniformity of pipe diameters in loop designs represented network performance and established a uniformity coefficient as the topological index. Ostfeld[31] later classified Water Distribution Network dependability assessments into topological, hydraulic, and entropic circumstances. Prasad et al.[32] explained how a multi-objective genetic algorithm built a water distribution network. This study aims to minimize network costs while increasing a reliability metric. The dependability metric used is network resilience, which evaluates both nodal excess power and the regularity of diameters linked to that junction. Improved network resilience improves a network's capacity to withstand failure circumstances. Al-Zahrani et al.[33] created an approach based on the minimal cut-set method that may be used to assess the hydraulic dependability of water circulation methods. Setiadi Y et al.[34] investigated the impact of forming mistakes on the link between entropy and hydraulic dependability in water dissemination methods. The hydraulic simulations were carried out using pressure-dependent analysis. The study concludes that the Entropy-reliability association is greater. Huang et al.[35] established the dependability of water distribution on water quality while considering the spread of water-borne illnesses. The simulation employs a scenario-based simulation method. Because of the growth in urban water consumption, it is vital to assume responsibility for delivering clean water. In future work, the research is carried out based on mechanical and hydraulic failure; there is no method for water dependability based on water quality. According to Yazdani et al.,[36] resilience is distinct as the volume to mitigate system failure's chance and effect and minimize total interrupted service during system disruptions.

Geometric research[37–39] was conducted within topological techniques, resulting in several metrics for measuring network dependability, including network efficiency, average degree, and link density. Javanbarg et al.[40] attempted to build a dependability valuation design of a water distribution method that took seismic threats and ways to improve hydraulic dependability. An ideal proposal model utilizes a harmony search approach to optimize seismic dependability with constrained funds (HS). The model is used in real-world water delivery systems to identify pipe widths that enhance seismic resilience. Gheisi and Naseret al.[41] identified the important aspects that might substantially impact the outcomes of a WDS reliability analysis. They identified the rate of pipe failure and pipe failure combinations, the dependability measure, and its criteria as the most relevant elements. Shuang et al.[42] looked at the cascading behaviours of Water distribution systems in fault conditions and how to identify crucial pipes. The damage to a specific pipe is used to measure the distribution of cascade faults in the water distribution system. Once the network has been restored to a stable condition, the system dependability is the identifying factor of critical pipes. The nodal pressure head, available water flow, daily demand multipliers, and topological structure were all evaluated in WDS's cascading failure simulation.

Furthermore, Prasad and Park[43] suggested a mixed reliability index, the network resilience index, which considers width regularity and the current resilience index. Furthermore, Jeong and Kang[44] proposed a hydraulic uniformity index, a composite dependability indicator that considers the regularity of hydraulic inclines of pipes inside a Water distribution system. Dziedzic et al.[45] presented a performance metric based on efficiency. Unlike prior dependability and resilience measurements, which assessed the new statistic additionally emphasizes the effectiveness of this distribution by highlighting the grid's volume to supply a particular set of streams and forces. The index incorporates four sub-metrics: dependability is the network's mean effectiveness under all circumstances; vulnerability is the network's lowest effectiveness; and resilience is the network's mean effectiveness after a failure (vulnerability) and connection, which is the least amount of flow supplied during a pipe burst. Gheisi A et al.[46] used a mathematical approach called aspect/state performance analysis to examine the performance dependability of the water distribution system. This analysis is performed under a variety of failure circumstances. However, this study does not address the combination of contemporary events and natural catastrophes, which is a disadvantage. Tanyimboh et al.[47] also explored the relationships between surrogate reliability metrics and surplus power factor with hydraulic reliability in fictitious Water distribution systems.

Pandit et al.[48] recommended analyzing the robustness of water supply systems and evaluating network design choices using multi-criteria analytics with network measurements. Every dimension is calculated as a dimensionless rate using linear alterations. For network plan options, the variance between the measured data and the maximum or minimum dimension rate among them over the distance between the maximum and minimum. Therefore, the structure resilience may be calculated as a particular number between 0 and 1 by adding the dimensionless standards of the metrics with weighting issues. Herrera et al.[49] planned a unique graph-theoretic technique for assessing resilience in large-scale water circulation systems. The suggested method is focused primarily on assessing the dismissal and capability of all feasible paths connecting demand nodes to their delivery streams'. Because it does not depend on exact hydraulic simulations, which need costly calibration methods and processing, this methodology scales well to large network topologies while remaining physically and topologically significant. Farahmandfar et al.[50] included duct dependability, well-defined as the likelihood of tube disaster, into the water network configuration's node degree. Chmielewski et al.[51] created a technique to model the resilience of water systems in a major earthquake; nevertheless, the method is comprehensive and may be used for a wide range of network systems and risks. The system works as a baseline predetermined hydrodynamic analysis on an entire water supply, concentrating on meaningful feature metrics (i.e., liquid water, volume, and quality); a stochastic analysis of the broken system, considering the property loss state and achievement level of each component; and a probabilistic analysis of the water system functionality, considering the physical damage analysis and recovery time of each component.

Dawidowicz et al.[52] explored dependability difficulties in countryside water supply schemes. Hydraulic calculations and the dependability of selected countryside water supply systems were used to prove the relationship between dependability stages, piping, and pipe size. According to Paez et al.,[53] the association among several files was investigated using five system architectures. Based on topological studies and hydraulic simulations, Kim et al.[54]

rationally established a system dependability methodology. The research was carried out with the minimal cut-sets to install a valve in both ends to overcome the loss of consumers due to pipe failure. Improving WDS dependability while working with a limited budget and on-site resources. This similar technique may be utilized as a future guideline to improve WDS dependability in the face of a restricted budget and site limitations. The dependability analysis of the water delivery network was described by Duan et al.[55] The EPANET model, based on cascading failure, is used to assess the water supply network's system dependability, node effect, and piping assessment.

Bonora et al.[56] showed applications of a novel mathematical framework based on a set of local surplus indicators. This framework allows for rewriting several well-known performance and energy indicators while also investigating particular components of the Water Distribution Networks. The assessments are accepted utilizing two different resolutive hydraulic methods: Demand-Driven Analysis and pressure-driven Analysis, common in software like the Environmental Protection Agency Network and WaterNetGen. Sirsant and Reddy[57] investigated the relationship between a dependability guide and hydraulic then motorized presentation using an ideally planned system using versatile tasks of the project price, entropy, resilience, and combination catalogues.

Emamjomeh et al.[58] investigated the dependability of water delivery networks. The suggested technique takes into account both mechanical and hydraulic uncertainty. The Weighted entropy-based metric is used in the study. It may be applied to a network that has missing pipes. As a result, it is utilized to determine the optimum mitigation strategy for various natural disasters such as earthquakes. Considering both systems, as mentioned earlier, features while assessing the dependability of water supply systems. Jeong et al.[59] compared reliability indices and hydraulic measures. Multi-criteria decision analysis is used to conduct an analysis (MCDA). Individual indexes are comprehensively valued. Comparative studies effectively index-building research that can better reflect varied network performances. And water managers for scenario construction that considers real-world operating settings and the selection of reliability indices and hydraulic measurements. Wang et al.[60] introduced the fuzzy set theory to investigate the dependability of the Water Distribution System and the accompanying belief degree (BD) of estimated dependability. The system dependability and BD of WDS were calculated using three degrees of uncertainty.

Furthermore, a sensitivity analysis of unknown individual components was also carried out to see how variables affected predicted dependability and related BD. The suggested technique can assist towns in developing specialized cylinder system software to increase WDS dependability. Berardi et al.[61] established a two-level mechanical reliability evaluation technique suitable for huge genuine Water Distribution Networks. It uses a path/connectivity-based approach to provide dependability signals for global-level analysis and regional selection of critical cases. Using the extended global gradient technique, the sophisticated hydraulic model features automated topological change detection and reliable modelling of water levels in tanks.

SUMMARY AND DISCUSSION

This article presents a comprehensive overview of the literature on WDS reliability analysis. The occurrence likelihood or levels of breakdown in tubes, pipeline failure combinations, and dependability criterion are the key factors that influence the dependability of WDS. The precision of the Water Distribution System's dependability conclusions and the state of the reliability assessment can be influenced by pipeline loss combinations. Failure can impact a Water Distribution System's operational presence in several ways simultaneously (e.g., amount, excellence, equity of delivered water, and water outflow). The Water Distribution System's failure has been researched for some time, and slight responsiveness has been made to how the scheme might simultaneously reply to a failure from many perspectives. A WDS's performance reaction to failure may be evaluated from various perspectives but not restricted to measurable and qualitative factors. Including a multi-aspect presentation reaction index in the Water Distribution System's dependability study can provide additional educational and truthful results. The supply ratio's single aspect performance response index is the maximum frequently used presentation index in simulation-based Water Distribution System's dependability techniques.

Without modeling the mechanics or quality of a WDS, analytical and heuristic WDS reliability study conclusions are possible, but they are less realistic than those achieved via a systemic-holistic approach. An analytical technique dissects a WDS into its fundamental parts and searches for connections between them. However, having a connection to a source does not ensure that a node will receive the requested water. Additionally, the resilience index is a metric that the heuristic reliability method assesses for the whole WDS and which researchers typically find to have a good link with the dependability of the WDS. The existence of such a substantial association between WDS reliability and the heuristic surrogate reliability measure (i.e., resilience index) is not, however, guaranteed to persist over time. In reality, heuristic metrics are not particularly significant.

As a result, resilience is associated with persistence, whereas stability refers to these systems' capacity to recover to a stable state following a brief disturbance. As a result, a stable system would not have substantial variations, but a robust system may. An entropy-based method employs Shannon's idea of information entropy. As a proxy dependability metric, entropy measures the quantity of accessible information about the water distribution in the Water Distribution Systems. Even more irregular and dispersed the flow of water output is spread in the tubes of a water distribution system, the larger the flow entropy. The WDS stream entropy can be increased by dismissal (the presence of additional flow paths) and stream homogeneity. Shannon's information entropy was utilized to assess dismissal and stream regularity in a Water Distribution system. A Monte Carlo framework methodology for estimating the regional and systemic hydrological reliabilities of water supply systems has been described. A methodology like this can evaluate existing systems, design new ones, and expand existing ones. Individual junction reliability might be readily enhanced, enhancing system dependability using the cut-set method.

Important network junctions must be recognized as a first step toward boosting system reliability. The piping impact on the dependability ideals of the intersections must be correctly preserved and substituted if required.[62,63]

Future Work

A computer-aided software, such as EPANET, WATERNETGEN, or WATERGEM, is used for most water distribution simulations. Consequently, parameters such as pressure, node height, pipe length, and pipe diameter may be obtained as output. A cut-set method, Multi-objective genetic algorithm, Demand-Driven Analysis and pressure-driven analysis, generalized global gradient algorithm, fuzzy set theory, Multi-criteria decision analysis, and Weighted entropy-based measure are some of the algorithms that are frequently used. The dependability of the water distribution system cannot be calculated using a specific approach. It is possible to utilize a mix of simulation and computed analytical technology. A large number of algorithms for computing are now available as open source.

Conclusion

There are no specific parameters or processes when evaluating the water delivery network's reliability. The researcher can select the water distribution network parameter for simulation and investigation. According to the paper, the researcher has numerous options for researching water network system reliability created on hydrological factors, unforeseen conditions such as natural disasters, and modelling and analytic approaches. The water distribution network study's dependability is entirely based on the researcher's concept and execution. The single-aspect performance response index of supply ratio is the performance index that is most frequently used in simulation-based WDS dependability techniques. This study brought attention to the literature's largely unmet demand for multiaspect and state performance analysis.

Although this research attempts to provide dependability and reliability-based design of WDSs, it does not cover all practical aspects. Additionally, a thorough discussion of research on the uncertainties in reliability assessment, as well as research on data collecting and reliability analysis confidence limitations, is required.

REFERENCE

1. A. Wildavsky. Searching for Safety; Transaction Books: New Brunswick. NJ, Canada **1988.**
2. L. Comfort. Shared Risk: Complex Systems in Seismic Response. Pergamon: New York, NY, USA **1999**.
3. H. R. Maier, B. J. Lence, B. A. Tolson, R. Foschi. First‐order reli ability method for estimating reliability, vulnerability, and resilience. *Water Resources Research* **2001**, 37(3), 779-790.
4. M. Bruneau, S. E. Chang, R. T. Eguchi, G. C. Lee, T. D. O'Rourke, A. M. Reinhorn, D. Von Winterfeldt. A framework to quantitatively assess and enhance the seismic resilience of communities. Earthquake spectra **2003,** 19(4), 733-752.
5. B. Xu, I. C. Goulter. Reliability-based optimal design of water distribution networks. *Journal of Water Resources Planning and Management* **1999,** 125(6), 352-362.
6. M. S. Marlim, G. Jeong, D. Kang. Identification of critical pipes using a criticality index in water distribution networks. *Applied Sciences* **2019**, 9(19), 4052.
7. I. Markov, M. Grigoriu, T. D. O'Rourke. An evaluation of seismic serviceability of water supply networks with application to the San Francisco auxiliary water supply system **1994**
8. M. Abdel-Wahed. Mustardé Versus Incisionless Otoplasty for Protruding Ear Mohamed Hassan Abdel-Aal, Mohammad Reda Ahmad, Mansour Mohamed Morsy, Mohamed Elsayed. Egyptian Journal of Hospital Medicine **2019**, 77(2).
9. M. Moghtaderi‐Zadeh, A. D. Kiureghian. Reliability upgrading of lifeline networks for post‐earthquake serviceability. *Earthquake Engineering, Structural Dynamics* 1983, 11(4), 557-566.
10. M. J. Cullinane. Reliability evaluation of water distribution system components. *In Hydraulics and hydrology in the small computer age* 1985, 353-358.
11. J. M. Wagner, U. Shamir, D. H. Marks. Water distribution reliability: analytical methods. *Journal of Water Resources Planning and Management* 1988, 114(3), 253-275.
12. R. G. Quimpo, U. M. Shamsi. Reliability-based distribution system maintenance. *Journal of Water Resources Planning and Management* 1991, 117(3), 321-339.
13. A. Li, T. Dolezal, Y. Y. Haimes. Capacity reliability of water distribution networks. *Reliability engineering, system safety* 1993, 42(1), 29-38.
14. S. J. Wu, J. H. Yoon, R. G. Quimpo. Capacity-weighted water distribution system reliability. *Reliability Engineering, System Safety* **1993**, 42(1), 39-46.
15. M. L. Kansal, A. Kumar, P. B. Sharma. Reliability analysis of water distribution systems under uncertainty. *Reliability Engineering, System Safety* **1995**, 50(1), 51-59.
16. S. Selcuk, M. S. Yücemen. Reliability of lifeline networks under seismic hazard. *Reliability Engineering, System Safety* **1999**, 65(3), 213-227.
17. T. T. Tanyimboh, R. Burd, R. Burrows, M. Tabesh. Modelling and reliability analysis of water distribution systems. *Water science and technology* **1999**, 39(40), 249-255.
18. L. W. Mays(Ed.). Reliability analysis of water distribution systems. ASCE Publications **1989**.
19. Y. Bao, L. W. Mays. Model for water distribution system reliability. *Journal of Hydraulic Engineering* **1990**, 116(9), 1119-1137.
20. K. Awumah, I. Goulter, S. K. Bhatt. Assessment of reliability in water distribution networks using entropy-based measures. *Stochastic Hydrology and Hydraulics* **1990**, 4(4), 309-320.
21. T. T. Tanyimboh, A. B. Templeman. Calculating maximum entropy flows in networks. *Journal of the Operational Research Society* **1993**, 44(4), 383-396.
22. E. Shannon. A mathematical theory of communication. *The Bell system technical journal* **1948**, 27(3), 379-423.
23. N. Raad, A. N. Sinske, J. H. Van Vuuren. Comparison of four reliability surrogate measures for water distribution systems design. *Water Resources Research* **2010**, 46(5).
24. J. M. Wagner, U. Shamir, D. H. Marks. Water distribution reliability: simulation methods. *Journal of water resources planning and management* **1998**, 114(3), 276-294.
25. T. D. Prasad, S. H. Hong, N. Park. Reliability-based design of water distribution networks using multi-objective genetic algorithms. *KSCE Journal of Civil Engineering* **2003**, 7(3), 351-361.
26. E. Todini. Looped water distribution networks design using a resilience index-based heuristic approach. *Urban water* **2000**, 2(2), 115-122.
27. L. D. F. Costa, F. A. Rodrigues, G. Travieso, P. R. Villas Boas. Characterization of complex networks: A survey of measurements. *Advances in physics* **2007**, 56(1), 167-242.
28. H. Liu, D. A. Savić, Z. Kapelan, E. Creaco, Y. Yuan. Reliability surrogate measures for water distribution system design: comparative analysis. *Journal of Water Resources Planning and Management* **2017**, 143(2), 04016072.
29. G. Jeong, A. Wicaksono, D. Kang. Revisiting the resilience index for water distribution networks. *Journal of Water Resources Planning and Management* **2017**, 143(8), 04017035.

30. T. D. Prasad, N. S. Park. Multi-objective genetic algorithms for design of water distribution networks. *Journal of water resources planning and management* **2004**, 130(1), 73-82.
31. A. Ostfeld. Reliability analysis of water distribution systems. *Journal of Hydroinformatics* **2004**, 6(4), 281-294.
32. T. D. Prasad, N. S. Park. Multi-objective genetic algorithms for design of water distribution networks. *Journal of water resources planning and management* **2004**, 130(1), 73-82.
33. M. A. Al-Zahrani, J. L. Syed. Evaluation of municipal water distribution system reliability using minimum cut-set method. *Journal of King Saud University-Engineering Sciences* **2005**, 18(1), 67-81.
34. Y. Setiadi, T. T. Tanyimboh, A. B. Templeman. Modelling errors, entropy and the hydraulic reliability of water distribution systems. *Advances in Engineering Software* **2005**, 36(11-12), 780-788.
35. J. Huang, E. McBean, W. James. A review of reliability analysis for water quality in water distribution systems. *Journal of Water Management Modeling* **2005**.
36. A. Yazdani, R. A. Otoo, P. Jeffrey. Resilience enhancing expansion strategies for water distribution systems: A network theory approach. *Environmental Modelling, Software* **2011**, 26(12), 1574-1582.
37. V. Latora, M. Marchiori. Efficient behaviour of small-world networks. *Physical review letters* **2001**, 87(19), 198701.
38. L. D. F. Costa, F. A. Rodrigues, Travieso, G., Villas-Boas, P. R. Characterization of complex networks: A survey of measurements. *Advances in physics* **2007**, 56(1), 167-242.
39. A. Jamakovic, S. Uhlig. On the relationships between topological measures in real-world networks. *Networks, Heterogeneous Media* **2008**, 3(2), 345.
40. M. B. Javanbarg, S. Takada. Seismic reliability assessment of water supply systems. *Safety, reliability and risk of structures infrastructures and engineering systems* **2010**, 3455-3462.
41. G. Jeong, D. Kang. Comparative Analysis of Reliability Indices and Hydraulic Measures for Water Distribution Network Performance Evaluation. *Water* **2020**, 12(9), 2399.
42. Q. S Huang, M. Zhang, Y. Yuan. Performance and reliability analysis of water distribution systems under cascading failures and the identification of crucial pipes. *PloS one* **2014**, 9(2), e88445.
43. E. Creaco, M. Franchini, E. Todini. The combined use of resilience and loop diameter uniformity as a good indirect measure of network reliability. *Urban Water Journal* **2016**, 13(2), 167-181.
44. G. Jeong, D. Kang. Hydraulic uniformity index for water distribution networks. *Journal of Water Resources Planning and Management* **2020**, 146(2), 04019078.
45. R. Dziedzic, B. W. Karney. Performance index for water distribution networks under multiple loading conditions. *Journal of Water Resources Planning and Management* **2016**, 142(1), 04015040.
46. A. Gheisi, M. Forsyth, G. Naser. Water distribution systems reliability: A review of research literature. *Journal of Water Resources Planning and Management* **2016**,142(11), 04016047.
47. T. T. Tanyimboh, C. Siew, S. Saleh, A. Czajkowska. Comparison of surrogate measures for the reliability and redundancy of water distribution systems. *Water Resources Management* **2016**, 30(10), 3535-3552.
48. A. Pandit, J. C. Crittenden. Index of network resilience for urban water distribution systems. *International Journal of Critical Infrastructures* 2016, 12(1-2), 120-142.
49. M. Herrera, E. Abrahama, I. Stoianov. A graph-theoretic framework for assessing the resilience of sectorized water distribution networks. *Water Resources Management* **2016**, 30(5), 1685-1699.
50. Z. Farahmandfar, K. R. Piratla, R. D. Andrus. Resilience evaluation of water supply networks against seismic hazards. *Journal of Pipeline Systems Engineering and Practice* **2017**, 8(1), 04016014.
51. H. Chmielewski, R. Guidotti, T. McAllister, P. Gardoni. Response of water systems under extreme events: a comprehensive approach to modeling water system resilience. *In World Environmental and Water Resources Congress* **2016**, 475-486.
52. J. Dawidowicz, A. Czapczuk. The reliability of rural water distribution systems in relation to the layout of the pipework within the network. *Czasopismo Techniczne* **2018**, 3, 141-151.
53. D. Paez, Y. Filion, C. R. Suribabu. Correlation analysis of reliability surrogate measures in real-size water distribution networks. *In WDSA/CCWI Joint Conference Proceedings* **2018**, vol. 1.
54. S. Kim, H. D.,Jun , D. G. Yoo, J. H. Kim. A framework for improving the reliability of water distribution systems based on a segment-based minimum cut-set approach. *Water* **2019**, 11(7), 1524.
55. X. Duan, Y. Zong, K. Hao, D. Huang, Y. Li. Research of hydraulic reliability of water supply network based on the simulation of EPANET. *In IOP Conference Series: Earth and Environmental Science* **2019**, 349(1), 012042.
56. M. A. Bonora, F. Caldarola, M. Maiolo. A new set of local indices applied to a water network through demand and pressure-driven analysis (DDA and PDA). *Water* **2020**, 12(8), 2210.
57. S. Sirsant, M. J. Reddy. Assessing the performance of surrogate measures for water distribution network reliability. *Journal of Water Resources Planning and Management* **2020**, 146(7), 04020048.
58. H. Emamjomeh, M. Hosseini. Reliability Assessment of Water Distribution Networks Considering Mechanical-Hydraulic Behavior Using Informational Entropy.
59. G. Jeong, D. Kang. Comparative Analysis of Reliability Indices and Hydraulic Measures for Water Distribution Network Performance Evaluation. *Water* **2020**, 12(9), 2399.
60. Y. Wang, G. Zhu. Analysis of reliability and belief degree for water distribution system based on fuzzy set theory. *Urban Water Journal* **2021**, 18(7), 497-509.
61. L. Berardi, D. Laucelli, F. Ciliberti, S. Bruaset, G. Raspati, I. Selseth, O. Giustolisi. Reliability analysis of complex water distribution systems: the role of the network connectivity and tanks **2022**, 24(1), 128-142.
62. D.-H. Cho. Evaluation of cooling efficiency improvement of the simple office for small factories using heat dissipation with cold water circulation. J. *Integr. Sci. Technol*. **2021**, 9 (1), 54–59.
63. D.-H. Cho. A study on the characteristics of Cooling Load due to the heat absorption of cold water circulating inside the Ocher Walls of small Cabins of one person. *J. Integr. Sci. Technol*. **2021**, 9 (1), 30–36.