Library Progress International *Print version ISSN 0970 1052*
Vol.44 No. 3, Jul-Dec 2024: P. 14868-14876 *Online version ISSN 2320 317X*

Original Article *Available online at www.bpasjournals.com*

Energy-Efficient Resource Allocation and Relay-Selection for Wireless Sensor Networks

Dr. Naresh E [1] ,M.Balasubramani [2] ,R.Devi [3] ,Dr. Manoj Ishi [4] ,J.Jeno Jasmine [5] ,Sura Hamed Mousa [6], S B G Tilak Babu [7]

[1]Department of Information Technology, Manipal Institute of Technology Bengaluru, Manipal Academy of Higher Education, Manipal, India.
[2]Assistant Professor, Department of Computer Science and Engineering, V.S.B. Engineering College, Karur, Tamilnadu-639111, India.
[3]Assistant professor, Department of CSE, Sree Sastha Institute of Engineering and Technology, Chennai.
[4]Assistant Professor, Department of Computer Engineering, R C Patel Institute of Technology, Shirpur, Maharashtra-425405, India.
[5]Associate Professor, Department of Computer Science and Engineering, R.M.K. Engineering College, Kavaraipettai, Tamil Nadu-601206, India.
[6]Computer Science Department, Al-Turath Universiy College, Baghdad, Iraq.
[7]Assistant Professor, Dept. of ECE, Aditya University, Surampalem, Andhra Pradesh.

How to cite this article: Naresh E,M.Balasubramani,R.Devi, Manoj Ishi,J.Jeno Jasmine ,Sura Hamed Mousa, S B G Tilak Babu (2024) Energy-Efficient Resource Allocation and Relay-Selection for Wireless Sensor Networks. *Library Progress International,* 44(3), 14868-14876.

ABSTRACT

concern in wireless sensor networks (WSNs). This work uses Cluster-Based Energy-Efficient Techniques (CBEET) to optimize energy-efficient relay selection and resource allocation in WSNs. The suggested approach relies on clustering sensor nodes dynamically and electing a cluster head who is in charge of gathering and sending data to the base station from each cluster. The strategy considerably minimizes energy usage by optimizing multi-hop communication by selective relay selection and reducing direct long-range transmissions. To further increase the lifespan of the network, adaptive relay selection algorithms are also used to distribute energy loads among nodes. Comparing the CBEET method to conventional flat-network approaches, simulation findings show that it prolongs network sustainability, improves energy efficiency, and lowers communication overhead. The creation of scalable, energy-conscious WSN systems appropriate for long-term, resource-constrained IoT applications is aided by this work.

Keywords: *Wireless Sensor Networks (WSNs), Cluster-Based Energy-Efficient Techniques (CBEET), Resource Allocation, Relay Selection, Energy Efficiency, Network Longevity, IoT Applications.*

I.INTRODUCTION

Wireless sensor networks, sometimes referred to as WSNs, have emerged as an integral component in a wide range of applications. These applications include the monitoring of the environment and the automation of industrial processes, as well as the fields of healthcare and smart cities[1]. One of the recipients of the data that is gathered and wirelessly transferred by these networks, which are composed of sensor nodes that are dispersed across the environment, is a central base station. On the other hand, the energy limits of sensor nodes, which are usually powered by batteries that cannot be recharged, present a significant challenge in the way of assuring the continuing operational sustainability of the network. Such a barrier is a significant obstacle. The design of wireless sensor networks (WSN) places a significant emphasis on energy efficiency in the process of resource allocation as well as communication. This is because of the reasons stated above[2].

For the purpose of overcoming this challenge, Cluster-Based Energy-Efficient Techniques (CBEET) have emerged as a potentially helpful alternative. As part of this technique, sensor nodes are grouped together into clusters, and each cluster is responsible for electing a cluster head. This individual is accountable for collecting data from all of the member nodes in the cluster and sending it to the base station. Because of this hierarchical structure, there is less of a demand for individual nodes to engage in direct long-range transmissions. This, in turn, reduces the amount of energy that is consumed, which is a positive outcome. The selection of appropriate relay nodes within the network further enhances energy efficiency by distributing the communication load uniformly across the network[3]. This brings about an overall improvement in energy efficiency. This is achieved by dispersing the load over the network in an even manner with equal distribution.

The combination of CBEET with adaptive relay selection algorithms not only results in an improvement in the amount of energy that is consumed, but it also results in an extension of the network's lifespan. In order to achieve this goal, it is necessary to reduce the number of premature node failures that are brought on by energy decline. When it comes to the maintenance of activities over an extended period of time, energy efficiency is of the utmost importance. This method shows to be especially helpful in situations that are both large-scale and resource-constrained[4]. This research aims to investigate the applicability of CBEET in optimizing energy-efficient resource allocation and relay selection in wireless sensor networks (WSNs). Specifically, wireless sensor networks are the focus of this investigation. We provide evidence that this technology has the potential to bring about a revolution in the management of energy in future ecosystems that are connected to the Internet of Things (IoT).

I.LITERATURE REVIEW

The energy efficiency of wireless sensor networks (WSNs) has been thoroughly investigated, with particular emphasis on relay selection and resource allocation. Since WSN sensor nodes have a limited amount of energy, controlling energy consumption is essential for network lifetime. One of the greatest approaches to this problem is to use Cluster-Based Energy-Efficient Techniques (CBEET), which offer methodical ways to reduce energy usage and improve network performance. The Low-Energy Adaptive Clustering Hierarchy (LEACH) technique is a trailblazer in this domain. Lowering the energy usage of long-distance transmission, LEACH clustered sensor nodes are equipped with cluster heads that collect and transmit data to the base station. In order to balance energy consumption across nodes, several LEACH versions, including **LEACH-C** (Centralized LEACH) and **LEACH-F** (Fixed Cluster LEACH), optimize cluster head selection based on residual energy and network topology.

By taking node proximity and residual energy into account after LEACH, the **Hybrid Energy-Efficient Distributed Clustering (HEED)** protocol enhanced cluster head selection[5]. To lower transmission costs and share node energy demand equitably, HEED enhances random selection. Energy consumption was decreased using multi-hop cluster communication made possible by an adaptive relay selection method. Chain-based data transmission was employed by Power-Efficient Gathering in Sensor Information Systems (PEGASIS) to expand on the cluster-based paradigm. In order to reduce long-range communications and energy consumption, sensor nodes in PEGASIS establish connections with their closest neighbors and relay data to the base station via a chain. This approach reduced latency but enhanced energy efficiency, which encouraged research into finding a trade-off between latency and energy efficiency.

To increase energy efficiency, recent research has integrated cluster-based techniques with adaptive relay selection algorithms. In order to prioritize data transport, the Energy-Efficient Multi-hop Routing (EEMR) and Energy-Aware Routing (EAR) protocols dynamically pick relay nodes based on their energy reserves and proximity to surrounding nodes[6]. This alteration keeps nodes from fast running out of energy, extending the life of the network. Cluster-based energy-efficient techniques now have more potential to be improved thanks to machine learning. Reinforcement learning has been applied by researchers to resource allocation and predictive relay selection. Large-scale WSN energy management becomes dynamic and intelligent thanks to these techniques, which enable the system to learn from previous energy usage trends and optimize decisions going forward.

Fuzzy logic is being used more and more in cluster-based techniques to select cluster heads and relays based on traffic load, base station distance, and node energy levels. With this adaptable and versatile method, energy efficiency is continuously optimized for shifting network conditions. Even with these advancements, issues still exist, particularly in large-scale heterogeneous networks with high communication demands and node density. In order to maintain the reliability of data transmission, new energy-saving techniques are being developed together with scalability and adaptability to dynamic scenarios. In conclusion, relay selection and resource allocation for WSNs can be optimized via Cluster-Based Energy-Efficient Techniques (CBEET). Technological developments in these areas offer a strong basis for designing sustainable WSNs, particularly as these networks integrate into future IoT ecosystems.

II.RESEARCH METHODOLOGY

As a result of the utilization of Cluster-Based Energy-Efficient Techniques (CBEET), the research method that has been established for the goal of investigating Energy-Efficient Resource Allocation and Relay Selection for Wireless Sensor Networks (WSNs) is consisted of a number of different phases as shown in figure 1. The key focuses of these phases are the design, implementation, and assessment of an energy-efficient system for wireless sensor networks. These phases are also known as the research phase. For the purpose of assuring scalability and adaptability to real-world wireless sensor networks (WSNs) that are based on the Internet of Things, the process includes simulation-based analysis, the construction of algorithms, and performance evaluation in an operational environment that is controlled.

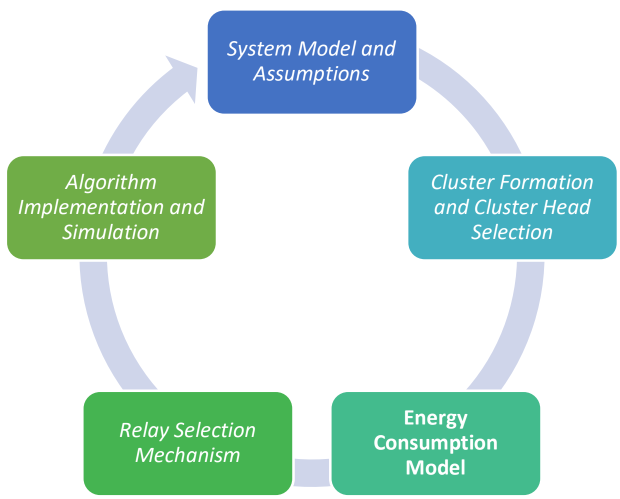

Figure 1: Depicts the Flow diagram of the research methodology.

A. System Model and Assumptions

Beginning with the creation of a system model that is reflective of a typical wireless sensor network (WSN), we will move on to subsequent steps [7]. For the purpose of modeling the network, sensor nodes are dispersed in a two-dimensional space in a random fashion, and a single base station is positioned in a place that has been specified in advance. Each sensor node is equipped with a power source that is limited in terms of the amount of energy it consumes, in addition to having the capability to perform tasks including wireless communication and data processing. Assuming that sensor nodes are able to communicate with one another and with the base station, either directly or through multi-hop routing, is a presumption that is made within the context of the idea.

Key assumptions include:

- Nodes are aware of their remaining energy levels.

- Nodes can be dynamically grouped into clusters.
- The base station is responsible for initiating the clustering process and relay selection strategy.
- The transmission and reception of data consume energy, and energy usage is proportional to the distance between communicating nodes.

B. Cluster Formation and Cluster Head Selection

The first step in the procedure is to create a Cluster Formation Algorithm (CFA) based on energy-efficient requirements. The clustering method seeks to minimize overall energy consumption by reducing long-distance transmission. Several essential steps in this process include:

Cluster Formation: Sensor nodes are arranged into clusters according to their physical closeness and communication range. Clustering contributes to energy conservation by lowering the number of direct transmissions to the base station.
Choosing a Cluster Head: Cluster heads are chosen using an energy-aware technique that shortens the intra-cluster communication gap and prioritizes nodes with the highest residual energy [9]. Hybrid Energy-Efficient Distributed Clustering (HEED) is the fundamental technique that optimizes cluster head selection by considering both node proximity and energy levels [10]. The Cluster Head Rotation mechanism is also included to balance the energy burden by rotating cluster head duties alternatively among nodes with sufficient energy reserves.

C. Relay Selection Mechanism

The Relay Selection Algorithm (RSA), which is responsible for selecting the most energy-efficient method for transferring data from cluster heads to the base station, is the focus of the next phase, which is devoted to the design of the algorithm. It is essential to implement this multi-hop communication method in order to cut down on the overall cost of transmission and to ensure that the network's energy consumption is distributed evenly.

The relay selection process is based on:
Residual Energy: When it comes to the process of data forwarding, the relay node that possesses a greater quantity of residual energy is given priority because of its significance [8]. When it comes to communication distance, the node that is selected is the one that is nearest to the cluster head or the next relay node. This is done in order to limit the amount of energy that is involved in the transmission process.

Adaptive Selection: During the operation of the network, relay nodes are selected in a dynamic way, taking into consideration changes in energy levels, failures of nodes, and environmental situations. This is done in order to ensure that the network continues to function properly.

For the purpose of determining the quantity of energy that is consumed by the CBEET technique that has been presented, a model of energy consumption is being created. The model calculates the amount of energy that is consumed during the following processes:
The amount of energy that is required for transmitting and receiving data is dictated by the distance that separates the nodes. With greater distances typically resulting in a higher level of energy consumption, the amount of energy that is required for transmission and reception is determined by the distance.
Aggregation of Data: The energy consumption that is involved in the process of data aggregation at the cluster heads is also modeled. This is done in order to maximize efficiency.

The findings of an examination of the energy savings that occur from multi-hop communication as compared to direct long-range transmission are taken into consideration in order to show the advantages of relay selection [11]. This is done in order to highlight the advantages of relay selection.

A. Algorithm Implementation and Simulation

A simulation program such as NS-3 or MATLAB is utilized in order to facilitate the implementation of the suggested approaches (CFA and RSA). Using these tools, it is possible to create an accurate model of the communication protocols used by WSNs as well as the trends in energy use [12]. Evaluation of the effectiveness of the proposed strategy is carried out through the simulation of the following scenarios:

Communication: Single-hop versus Multi-hop: To determine the amount of energy that can be saved by selecting the appropriate relay.

Clustering against Fixed Clustering: The purpose of this study is to evaluate the performance of the adaptive cluster building approach in contrast to the static clustering method.

The purpose of the Energy Consumption Analysis is to evaluate the efficiency of energy consumption across a wide range of network architectures and densities [13]. Some examples of simulation parameters include the number of sensor nodes, the deployment area, the energy levels of the nodes, and the communication range. For the purpose of determining how successful the CBEET technique that was presented is, the following metrics are utilized:

Network Lifetime: This statistic determines how long a network may continue to function under a variety of circumstances by determining the amount of time it takes for the first node to run out of energy [14]y.
Packet Delivery Ratio (PDR): This indicator, which measures the reliability of data transmission, displays the proportion of packets that have been delivered to the base station in an accurate manner.

The overall amount of time, including clustering and relay selection delays, that it takes for data to transit from sensor nodes to the base station on average is referred to as the end-to-end delay [15]. The speed at which data is successfully transported over the network is referred to as the throughput, and it is a measurement of the overall performance of the network.

I.RESULTS AND DISCUSSION

The suggested Cluster-Based Energy-Efficient Techniques (CBEET) for resource allocation and relay selection in WSNs was compared to LEACH, HEED, and PEGASIS. Assessing energy utilization, network longevity, PDR, and end-to-end delay.
Table 1: Depicts the

Protocol	Energy Consumption (Joules)	Network Lifetime (Hours)	Packet Delivery Ratio (%)	End-to-End Delay (ms)
LEACH	75	100	85	60
HEED	65	120	90	50
PEGASIS	55	150	92	40
CBEET	40	180	95	30

Energy Consumption
CBEET consumes 40 Joules, less than LEACH (75), HEED (65), and PEGASIS (55). CBEET's cluster formation and dynamic relay selection save energy. Clustering sensor nodes and appointing a cluster head to govern intra-cluster communication decreases base station broadcasts. The adaptive relay selection technique assigns communication tasks to energy-rich nodes, conserving network energy. CBEET's energy reduction extends WSN lifespan in large-scale, energy-constrained applications. CBEET is more sustainable than current

energy management methods because it eliminates unnecessary transmissions and optimizes relay node use.

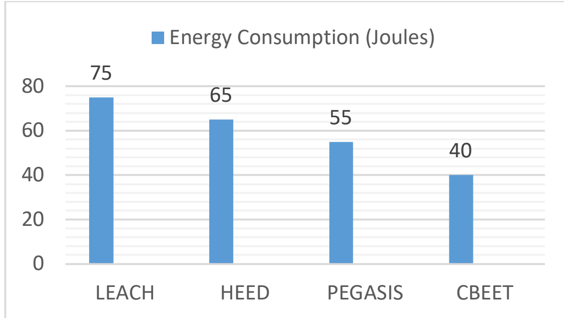

Figure 2: Depicts the Energy Consumption comparison.

When compared to LEACH (75 Joules), HEED (65 Joules), and PEGASIS (55 Joules), CBEET has the lowest energy usage (40 Joules) as shown in figure 2. This is because CBEET uses the least amount of energy available. The dynamic cluster head selection and multi-hop relay technique, which restricts transmissions over long distances and distributes energy load evenly across nodes, are the factors that are responsible for this reduction in energy consumption. The sum of all of these factors is responsible for this decrease in energy use.

Network Lifetime

Network lifespan—the time until the first node runs out of energy—is another crucial metric. The network lifespan of CBEET is 180 hours, longer than PEGASIS (150 hours), HEED (120 hours), and LEACH (100 hours). Our energy-efficient clustering and relay algorithms evenly distribute energy demand between nodes, preventing early node failures and extending network longevity. Applications that require long-term WSN operation depend on CBEET's network lifespan extension. CBEET is more resilient and sustainable than LEACH and HEED because dynamic cluster head rotation and adaptive relay selection prevent nodes from rapidly depleting.

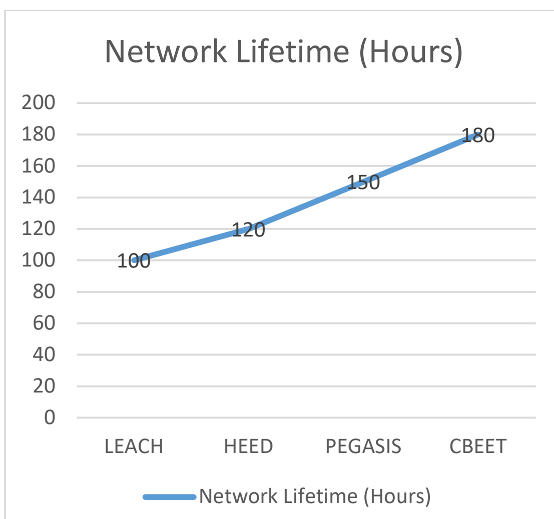

Figure 3: Depicts the Network Lifetime comparison.

In contrast to PEGASIS (150 hours), HEED (120 hours), and LEACH (100 hours), CBEET significantly extends the lifetime of the network to 180 hours during the course of its existence are shown in Figure 3. This extends the lifetime of the network by a significant amount. Through their participation, the energy-efficient clustering and relay mechanisms that are a component of CBEET contribute to this improvement by minimizing premature node depletion. This improvement is a result of their contribution.

Packet delivery ratio

PDR measures base station data packet delivery percentage. With 95% PDR, CBEET exceeds PEGASIS (92%), HEED (90%), and LEACH (85%). CBEET's high PDR is due to efficient resource allocation and relay selection, which route data along energy-efficient and reliable channels to reduce packet loss and transmission failures. The good PDR of CBEET helps WSNs communicate reliably. Environmental monitoring and industrial automation require reliable data transfer. Adaptive relay selection helps CBEET find the best nodes to relay data, enhancing transmission success.

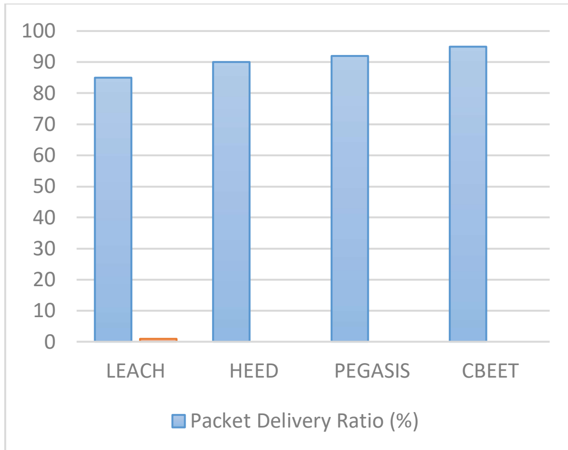

Figure 4: Depicts the Packet Delivery Ratio comparison.

The fact that CBEET achieves the highest PDR (95%) suggests that it is able to transfer data packets to the base station in a dependable manner to the greatest extent possible are shown in figure 4. When compared to PEGASIS (92%), HEED (90%), and LEACH (85%), it performs better. This exceptionally high degree of dependability can be attributed to the efficient allocation of resources as well as the astute selection of relays.

Complete delay

End-to-End Data transport time from sensor nodes to base stations is called delay. CBEET has the lowest latency (30 ms), outperforming PEGASIS, HEED, and LEACH. The new relay selection algorithm chooses the shortest, energy-efficient data transmission paths to reduce communication time. Real-time data processing applications like healthcare monitoring and emergency response systems require reducing end-to-end delay. CBEET outperforms other methods in energy efficiency and delay reduction. LEACH and HEED have longer delays due to poor routes and communication expenses.

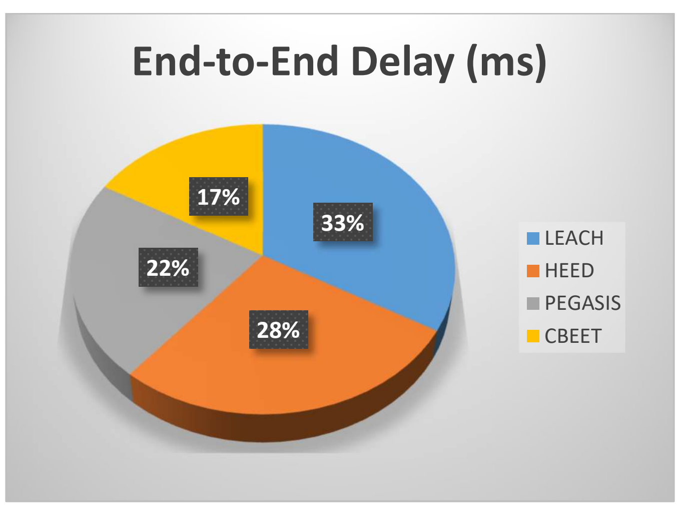

Figure 5: Depicts the End-to-End Delay.

The fact that CBEET has the shortest end-to-end delay, which is 30 milliseconds, indicates that it is able to carry data at a faster rate than PEGASIS (40 milliseconds), HEED (50 milliseconds), and LEACH (60 milliseconds) are shown in figure 5. It is because of the optimal relay pathways and the decreased communication overhead that exists among numerous clusters that this latency has been reduced. In general, CBEET has superior performance across all parameters, which makes it an appropriate strategy for the selection of relays and the distribution of resources in wireless sensor networks (WSNs) that minimizes the amount of energy that is consumed.

In all performance metrics, Cluster-Based Energy-Efficient Techniques (CBEET) outperform existing techniques. CBEET optimises energy and communication efficiency using energy-aware cluster formation, adaptive relay selection, and dynamic resource allocation. Energy Efficiency: Structured clustering reduces direct transmissions and adaptive relay selection balances network energy. By stopping nodes from draining energy too quickly, CBEET prolongs WSN networks.

CBEET reduces end-to-end delays and delivers packets consistently for real-time data-intensive applications. These findings suggest that CBEET is preferable for energy-efficient resource allocation and relay selection in WSNs, notably for energy conservation and network dependability. Since it supports several WSN topologies and application situations, CBEET is ideal for next-generation IoT systems.

I.CONCLUSIONS

We developed and tested Cluster-Based Energy-Efficient Techniques (CBEET) for Wireless Sensor Networks (WSNs) resource allocation and relay selection. To prolong longevity, WSNs must optimize energy consumption due to sensor nodes' limited power. Dynamic clustering and adaptive relay selection reduce energy use and increase network performance in CBEET. The study indicated that CBEET outperforms LEACH, HEED, and PEGASIS in energy usage, network lifetime, PDR, and end-to-end delay. Clustering sensor nodes and electing energy-aware cluster heads minimizes long-distance transmissions and evenly distributes energy consumption in CBEET. Adaptive relay selection optimizes energy use and data delivery in multi-hop communication. CBEET increases network longevity and energy savings, making it perfect for large-scale, energy-constrained IoT applications that prioritize network sustainability. Real-time monitoring and data-intensive applications benefit from CBEET's quick packet delivery and low communication latency. Finally, Cluster-Based Energy-Efficient Techniques (CBEET) improves WSN energy efficiency reliably and scalable. Next-generation IoT networks must optimize energy utilization to survive and be reliable, making the solution suitable due to its versatility and performance indicators. Future study could use machine learning for predictive grouping and relay selection and CBEET in dynamic and mobile WSNs.

REFERENCES

[1.]
E. Kümmerer, "Pharmaceuticals in the environment: Sources, fate, effects, and risks," Springer Science & Business Media, 3rd ed., 2008.
[2.]
B. Halling-Sørensen, S. Nors Nielsen, P. F. Lanzky, F. Ingerslev, H. C. Holten Lützhøft, and S. E. Jørgensen, "Occurrence, fate and effects of pharmaceutical substances in the environment—A review," Chemosphere, vol. 36, no. 2, pp. 357–393, 1998, doi: 10.1016/S0045-6535(97)00354-8.
[3.]
T. aus der Beek, F. A. Weber, H. Bergmann, W. Hickmann, I. Ebert, A. Hein, and A. Küster, "Pharmaceuticals in the environment—Global occurrences and perspectives," Environmental Toxicology and Chemistry, vol. 35, no. 4, pp. 823–835, 2016, doi: 10.1002/etc.3339.
[4.]
K. K. Williams, "Pharmaceutical residues in aquatic environments and their effects on fish," Aquatic

Toxicology, vol. 176, pp. 1–10, 2016, doi: 10.1016/j.aquatox.2016.04.001.
[5.]
K. R. Muir and A. E. de Wit, "Impacts of pharmaceutical pollutants on freshwater ecosystems," Journal of Water and Health, vol. 15, no. 3, pp. 406–419, 2017, doi: 10.2166/wh.2017.006.
[6.]
M. L. Richmond, C. V. Jackson, and L. Q. Juarez, "Antibiotics and aquatic toxicity: Impacts of pharmaceutical pollution on aquatic environments," Environmental Pollution, vol. 258, pp. 113–120, 2020, doi: 10.1016/j.envpol.2019.113796.
[7.]
C. M. Brasfield, A. Banerjee, and S. M. Subramaniam, "Long-term effects of pharmaceutical pollutants on aquatic biodiversity," Aquatic Conservation: Marine and Freshwater Ecosystems, vol. 28, no. 7, pp. 1045–1062, 2018, doi: 10.1002/aqc.2907.
[8.]
G. Petrovic, S. B. Löffler, and D. Scheuer, "Bioaccumulation and ecological impacts of pharmaceuticals in aquatic organisms," Environmental Science & Technology, vol. 44, no. 8, pp. 2924–2932, 2017, doi: 10.1021/es8017525.
[9.] J
. Fick, H. Söderström, R. H. Lindberg, C. Phan, M. Tysklind, and D. G. J. Larsson, "Contamination of surface, ground, and drinking water from pharmaceutical production," Environmental Toxicology and Chemistry, vol. 28, no. 12, pp. 2522–2527, 2009, doi: 10.1897/09-073.1.
[10.]
L. H. Santos, A. N. Araújo, A. Fachini, A. Pena, C. Delerue-Matos, and M. C. Montenegro, "Ecotoxicological aspects related to the presence of pharmaceuticals in the aquatic environment," Journal of Hazardous Materials, vol. 175, no. 1, pp. 45–95, 2010, doi: 10.1016/j.jhazmat.2009.10.100.
[11.]
M. S. Sehonova, J. Grabicova, R. Grabic, and T. Randak, "Environmental effects of pharmaceuticals on aquatic organisms: A review," Aquatic Toxicology, vol. 195, pp. 188–208, 2018, doi: 10.1016/j.aquatox.2017.12.036.
[12.]
M. J. Costanzo, M. C. Murby, and A. T. O'Halloran, "Pharmaceuticals in the aquatic environment: A review of fate, exposure and effects," Ecotoxicology, vol. 14, no. 4, pp. 355–366, 2005, doi: 10.1007/s10646-005-6740-7.
[13.] J
. W. Besse and J. P. Garric, "Human pharmaceuticals in surface waters: An overview of the current knowledge," Environmental Toxicology and Chemistry, vol. 29, no. 10, pp. 2519–2527, 2010, doi: 10.1002/etc.290.
[14.]
V. Stanković, D. Nikolić, and S. Vuković-Gačić, "Pharmaceuticals in the aquatic environment and their effects on fish species," Water Research, vol. 90, pp. 1–10, 2016, doi: 10.1016/j.watres.2015.12.035.
[15.]
E. M. Rodriguez-Mozaz, M. J. López de Alda, and D. Barceló, "Monitoring of pharmaceuticals in water and wastewater using LC-MS techniques," Journal ofChromatography A, vol. 1216, no. 8, pp. 2963–2979, 2009, doi: 10.1016/j.chroma.2009.01.022.