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Original Article

Demystifying the Role of AIoT for Sustainable WASH Conditions: Analysis and Research Directions

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Abstract *- With increasing population, expanding human activities and the effects of climate change, ensuring adequate Water, Sanitation, and Hygiene (WASH) conditions are crucial for the healthcare, development and well-being of nations and their citizens. The inclusion of WASH within the Sustainable Development Goals (SDGs) reflects the need to adopt innovative approaches for providing the necessary WASH infrastructure and services. Data Analytics on the WASH indicators help monitor the progress of WASH initiatives, infrastructure availability and conditions, service levels, WASH-related behavior changes, etc. and guide the development of early warning systems. Hence, this work applies Data Analytics on the WASH records from the WHO/UNICEF Joint Monitoring Programme (JMP) to enable efficient and effective WASH analysis and interventions. Further, the advances in Artificial Intelligence (AI) and Internet of Things (IoT) technologies and their amalgamation as Artificial Intelligence of Things (AIoT) have the potential to bring transformative changes to WASH practices. This work presents various research directions for addressing the challenges in the WASH sector by implementing AI algorithms on real-time data procured by IoT devices. These AIoT research directions contribute to developing a sustainable WASH ecosystem by enhancing efficiency, identifying indicative patterns, and enabling data-driven decision-making.*

Keywords *- Sustainability, Artificial Intelligence, Internet of Things, AIoT, Water, Sanitation, Hygiene.*

1. Introduction

Water, Sanitation, and Hygiene (WASH) [1], [2] conditions refer to the availability and quality of water, sanitation services, and hygiene practices. With ever-growing populations, increasing human activity, and climatic variation, assuring adequate WASH conditions is of immense importance for developing the nation and its citizens but is expected to become extremely challenging in the coming decades [3]. Addressing this issue has achieved consensus and has been included in the Sustainable Development Goals (SDGs) set by the United Nations' Agenda 2030 [4]. Specifically, SDG 6 aims to ensure WASH's availability and sustainable management. Understanding the three aspects of WASH for sustainable development is crucial and introduced in this section.

1.1. Clean Water for Sustainable Development

One of the most pervasive challenges affecting human and planetary well-being is inadequate access to clean water [5-7]. The following sectors have a major dependence on clean water:

1.1.1. Healthcare

Contaminated water can spread diseases such as diarrhoea, cholera, typhoid, dysentery, etc. Despite advances in healthcare, lack of access to clean water is a leading cause of illness and death in many parts of the world.

1.1.2. Agriculture

Around 70% of global water withdrawals are for agricultural purposes. Clean water is essential for ensuring sustainable agriculture and food production, and poor water quality can reduce crop yields and threaten food security.

1.1.3. Ecosystem Preservation

Water pollution has devastating effects on aquatic life, causing declines in underwater habitat populations. Many freshwater habitats provide essential ecosystem services, such as water filtration and flood control, vital for human well-being.

1.1.4. Economic Growth

Several industries require large amounts of clean water to operate efficiently and ensure required productivity. The unavailability of clean water may result in production delays and increased costs, ultimately leading to decreased economic growth.

1.1.5. Climate Change

Climate change is exacerbating water scarcity and quality issues. Access to clean water is essential to survive and adapt to these changing conditions, such as rising temperatures and extreme weather events like heat waves and droughts.

These requirements demand the creation of sustainable and affordable solutions for universal access to clean water.

1.2. Sanitation Facilities for Sustainable Development

The provision of adequate sanitation facilities, such as toilets, handwashing stations, and wastewater treatment systems, is critical for promoting sustainable development in the following aspects [8], [9]:

1.2.1. Improving Public Health

Access to proper sanitation facilities can significantly reduce the spread of waterborne diseases such as diarrhoea, cholera, etc. This improved public health leads to a more productive workforce and the nation's progress.

1.2.2. Reducing Poverty

Poor sanitation is a leading cause of poverty, particularly in developing countries. By investing in sanitation infrastructure, governments and businesses can help to reduce poverty, decrease healthcare costs, and promote tourism and overall economic growth.

1.2.3. Protecting the Environment

Poor sanitation can also negatively impact the environment, such as contamination of water sources and soil degradation. Investing in sustainable sanitation solutions such as composting toilets and wastewater treatment plants can protect the environment while promoting public health.

1.2.4. Assuring Dignity and Safety

Lack of sanitation facilities leading to open defecation has severe consequences on individual dignity and safety, particularly for women and girls. Traveling long distances to access safe and clean toilets makes them vulnerable to physical and sexual assault. This also has a huge impact on their mental and emotional well-being and overall safety. Improving sanitation technology and finding effective, sustainable solutions are crucial for addressing sanitation challenges like open defecation.

1.3. Hygiene Practices for Sustainable Development

Personal and public hygiene are crucial for maintaining a healthy and safe environment for individuals and communities. This also involves proper disposal of waste and faeces, garbage segregation and recycling, regular disinfection and maintenance of water reservoirs, and ensuring clean and safe food handling practices in kitchens [10], [11]. The following requirements are addressed by adopting good hygiene practices:

1.3.1. Improved Health and Well-being

Hygiene practices help prevent disease and infection spread. This can lead to improved health and well-being for individuals and communities, which can, in turn, support broader development outcomes such as increased productivity and economic growth.

1.3.2. Environmental Sustainability

Proper hygiene practices can help prevent pollution and the spread of waste and contaminants, which can negatively impact the environment and contribute to climate change. Promoting waste management practices shall protect natural resources for future generations.

1.3.3. Saving Resources

By practicing good hygiene, communities can reduce the use of resources like water and energy. For example, water conservation measures like repairing leaks and using low-flow toilets can save significant amounts of water, which can be particularly important in water-stressed areas.

Investing in hygiene infrastructure, promoting behaviour change for hygiene practices, and working collaboratively with stakeholders for hygiene assurance is essential.

The continuance of WASH-related issues and excessive loss of life in modern times is evidence of the need to improve this public health risk and, hence, is the subject of this work.

The paper is organized as follows: Section II presents Data Analytics on WASH conditions worldwide. A brief description of Artificial Intelligence of Things (AIoT) is presented in Section III. Research directions to strengthen WASH using Artificial Intelligence and the Internet of Things are presented in Section IV. Section V concludes the work.

2. Data Analytics

It is crucial to perform data analytics on the areas needing improvement in WASH services as it helps allocate resources and develop strategic plans. Tracking changes in the WASH indicators over time can determine if plans are making a positive impact.

Further, data analytics also helps monitor disease outbreaks, identify areas where outbreaks occur, develop targeted interventions to prevent the spread of disease, determine resources needed to meet the WASH needs of different communities, policy development and decision-making, etc.

WASH services have been core health and socio-economic indicators used by UNICEF, and the WHO/UNICEF Joint Monitoring Programme (JMP) captures progressive tracking of universal access to WASH services for benchmark and progress comparison between countries. Detailed analysis of JMP data [12] is conducted to realize the actual availability scenario. Fig. 1 describes the progression of WASH services worldwide in the last decade. Although an improvement is seen for each of the elements, the coverage in rural areas requires significant attention.

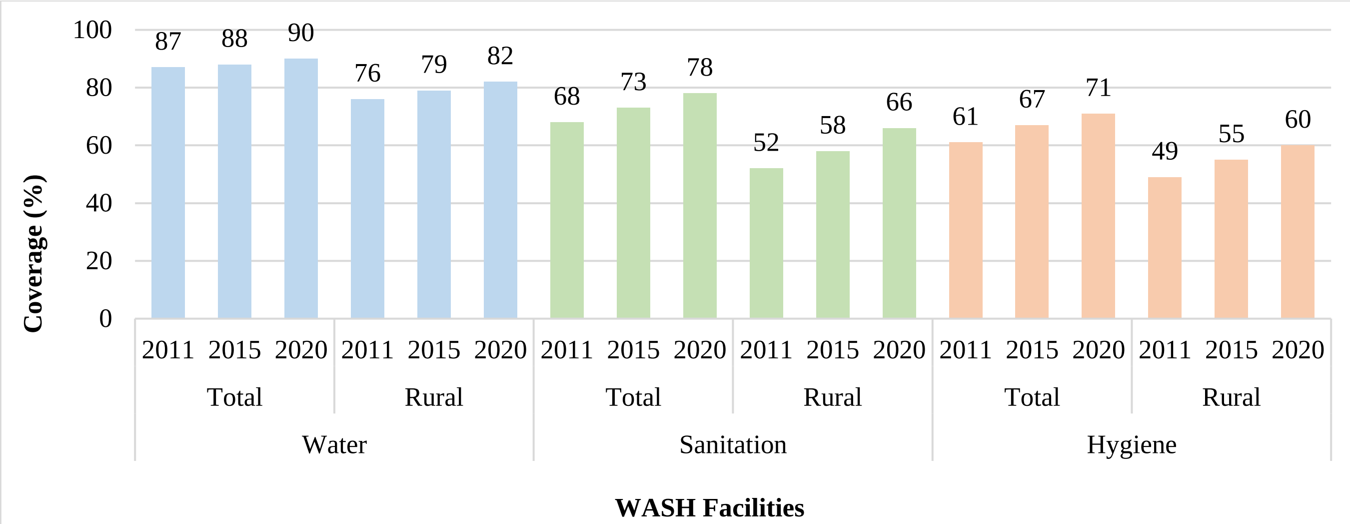

Fig. 1 Analytics on progression of WASH services in the world

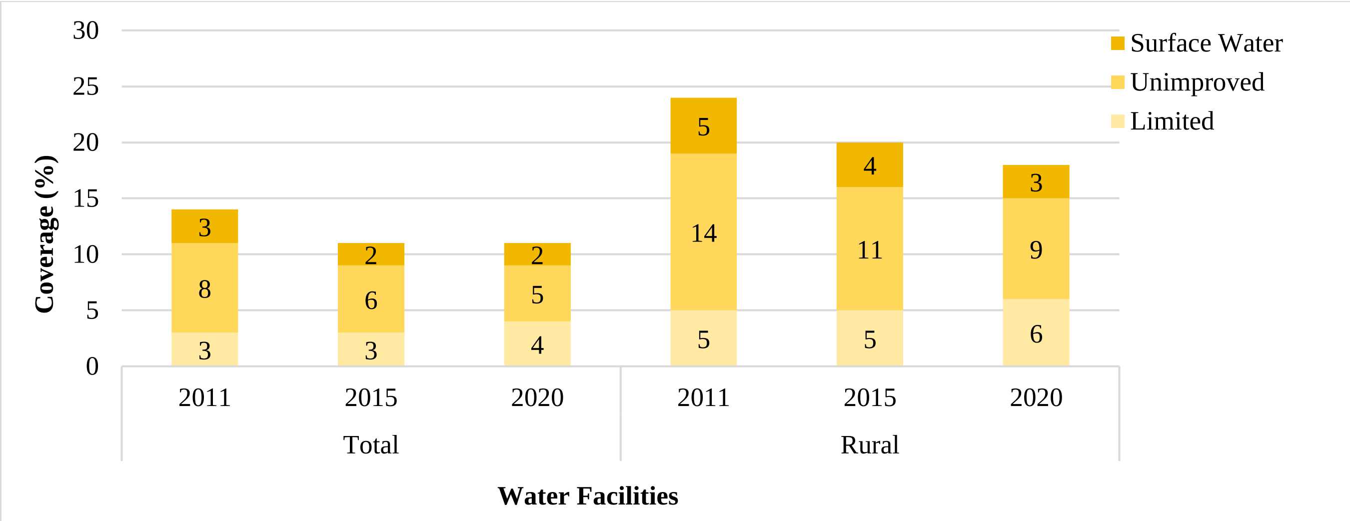

Fig. 2 Analytics of population lacking water facilities

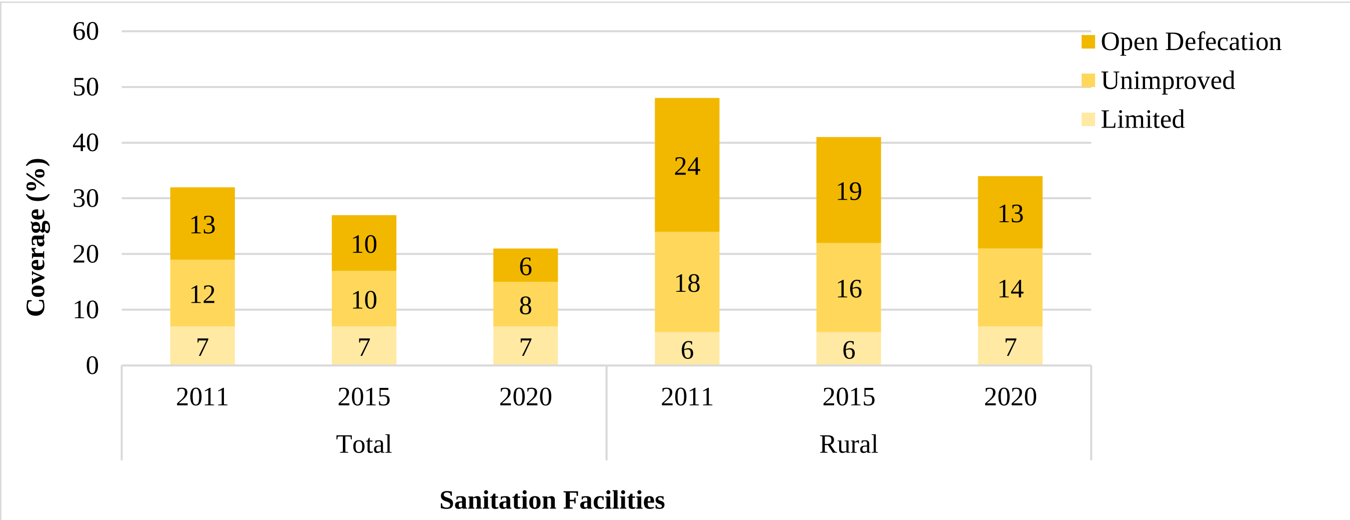

Fig. 3 Analytics of population lacking sanitation facilities

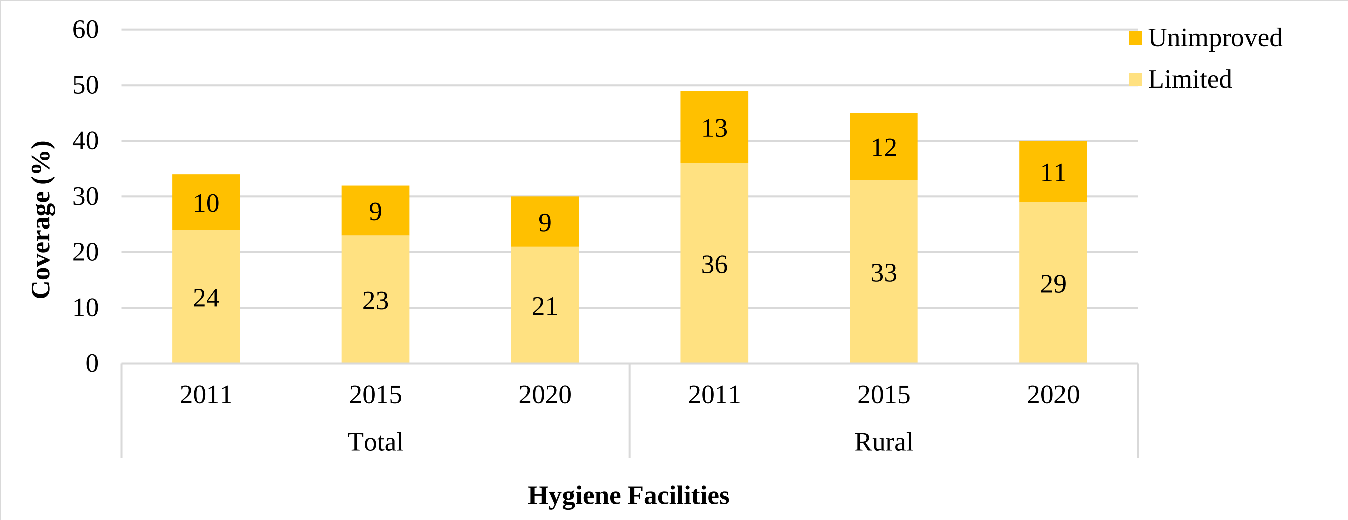

Fig. 4 Analytics of population lacking hygiene facilities

Figure 2 to Fig. 4 present the analysis of the population (coverage in %) lacking availability of water, sanitation, and hygiene facilities, respectively, for the years 2011, 2015, and 2020.

Figure 2 shows that in 2020, 10% of the total population and 18% of the rural population lacked access to basic drinking water facilities. Further, no improvements are observed for 9% of the rural population in that lustrum, whereas 6% of the rural population have limited access to water, which is alarming.

Figure 3 presents the statistical analysis of the population with limited access to sanitation facilities / unimproved facilities over the decade / who still defecate in the open. As observed, 27% of the rural population defecating in the open or with unimproved facilities calls for an immediate intervention, wherein technology can play a vital role.

Further, Figure 4 depicts that as of 2020, 21% of the total population and 29% of the rural population still have access to limited hygiene facilities. In addition, despite several hygiene initiatives, no service improvement is made for 9% of the total population and 11% of the rural population.

It is noteworthy that while water and sanitation facilities have improved over the decade, the hygiene facilities need tremendous improvement. Overall, the unavailability of WASH depicted through this data analysis indicates the pressing need for research and innovative solutions in this area, which is presented in the next section.

3. Artificial Intelligence of Things

The state-of-the-art technologies of Artificial Intelligence and the Internet of Things have profoundly influenced several sectors through definite solutions. These technologies and their amalgamation as Artificial Intelligence of Things can also be applied to address WASH conditions [13, 14]. A brief description of these technologies is presented herein.

3.1. Artificial Intelligence

Artificial Intelligence (AI) [15], [16] aims to develop machines that perform tasks that typically require human intelligence, such as learning from past experiences, understanding natural language, and recognizing images. AI systems can process huge amounts of data, learn patterns, make predictions based on that data, and support decision-making. It is a broad field encompassing several sub-disciplines, including Machine Learning, Natural Language Processing, Computer Vision, Deep Learning, Robotics, etc.

Systems based on AI technology are rapidly evolving, and their capabilities are increasing at a remarkable pace with numerous applications in diverse fields, such as healthcare, agriculture, finance, communication, transportation, entertainment, etc.

3.2. Internet of Things

The Internet of Things (IoT) [17], [18] is a network of physical objects or "things" that are embedded with sensors, software, and connectivity, thus allowing them to collect and exchange data with other devices and systems over the internet. These devices can be everyday-used entities, such as cars, appliances, and wearables, as well as industrial equipment and infrastructure.

The IoT ecosystem comprises four main components: the devices or things, the connectivity between them, the data they generate, and the applications and services that make use of that data. IoT devices can collect continuous data, such as temperature, humidity, location, movement, and other environmental factors, which can be analyzed and used to improve efficiency, reduce costs, and enhance user experiences.

3.3. Amalgamation of AI and IoT

Artificial Intelligence of Things (AIoT) refers to the integration of Artificial Intelligence (AI) technologies with the Internet of Things (IoT) ecosystem to collect, transfer, and analyze data using AI algorithms and make intelligent decisions based on the insights gained. AIoT systems can optimize processes, improve efficiency, and enhance the end-user experiences. AIoT combines the real-time data processing capabilities of IoT with the decision-making and predictive power of AI, creating a more intelligent and efficient system. Following are the benefits of Artificial Intelligence of Things (AIoT), which can influence various industries and sectors in different ways [19]-[22]:

3.3.1. Improved Efficiency

AIoT can automate many processes, thereby minimizing errors and reducing human intervention. For instance, AIoT can help optimize production processes and reduce downtime in a manufacturing plant by predicting when maintenance is needed.

3.3.2. Enhanced Decision-Making

The combination of AI and IoT technologies can enable decisions based on real-time data. In applications such as smart homes, an AIoT-enabled device can learn user preferences and automatically adjust settings to optimize energy consumption and improve user experience.

3.3.3. Predictive Maintenance

AIoT can predict when any machine or equipment requires maintenance, thus reducing downtime and minimizing the risk of breakdowns. For instance, in a transportation system, AIoT can predict when a vehicle requires maintenance, ensuring it is done before the vehicle breaks down, reducing the risk of delays.

3.3.4. Personalization

AIoT can enable devices to learn user preferences and accordingly provide personalized experiences. In healthcare, AIoT devices can monitor patients' vital signs, detect early signs of disease, and provide personalized treatment options based on individual data.

3.3.5. Improved Security

AIoT can enhance security by detecting anomalies and unusual patterns in data collected from IoT devices. For instance, AIoT can detect unusual activities in a smart home and alert homeowners of potential security threats. Integrating AI with IoT devices makes it possible to create smarter, more autonomous systems that can adapt and respond to changing conditions, automate and optimize processes, improve efficiency, enhance user experiences and optimize performance over time.

4. Research Directions

AIoT has the potential to model and overcome the challenging issues with WASH conditions through their generalization, cost-effectiveness, and resilience to achieve sustainable solutions. Some such research directions are described in this work for further specialized investigation and implementation.

4.1. AIoT for Sustainable Water Facilities

As per the survey by the United Nations [4], approx. 3 Billion people in the world are not aware of the quality of water they use. Further, it is analyzed that at the current rate of progress of WASH initiatives, approx. 1.6 Billion people will lack access to safely managed drinking water even in 2030. To accomplish the SDG targets, AIoT-based technological interventions for monitoring the water quality and managing water resources, as depicted in Fig. 5, shall be impactful.

The automated AIoT-based solutions are low-cost and shall reduce the requirement of manual testing, save time, and notify the concerned authorities through Mobile/Web applications to enable prompt remedial action.

AIoT can be used to monitor the water quality in real-time remotely using sensors such as temperature sensors, pH sensors, turbidity sensors, dissolved oxygen sensors, etc. Classification techniques like Decision Trees, Artificial Neural Networks, etc., can be implemented for classification and can be used for continuous monitoring, forecasting containment levels, altering when the levels exceed the thresholds, and ultimately maintaining compliance with water-quality standards.

The colour of water indicates the presence of chemical substances and is useful to determine the nature and level of water pollution. Images of water scanned using an image sensor/camera can be used to analyze water colorization and monitor red tides through the application of Image Processing techniques for further notifying the water requiring treatment.

Further, AI can be applied to data retrieved from IoT devices through water sensors, water level/depth sensors, water flow sensors, etc., to manage water resources. Time-series data Analytics and Prediction can be applied to the water availability data from these sensors, along with data on population, usage patterns, etc., to monitor water usage and forecast water scarcity conditions or corresponding requirements.

AI can be further used in the early prediction of pipes, pumps, valves, etc., failures, which are the key reasons for water loss based on values recorded by IoT devices. AIoT can also be employed for condition-based maintenance of water infrastructure, wherein leakage in storage tanks can be predicted, and the repair can be done in time to prevent water wastage. Altogether, these AIoT solutions can help plan, implement, and track water-resource management strategies.

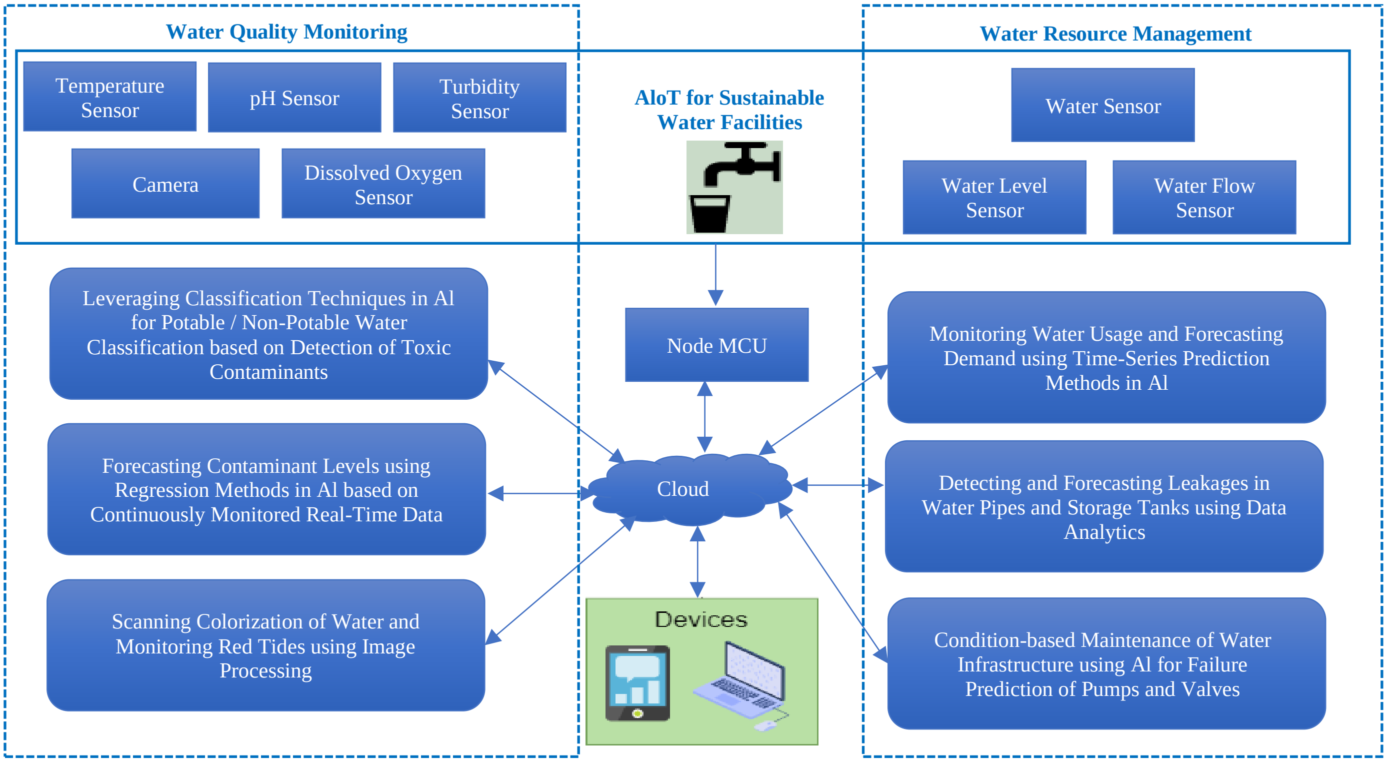

Fig. 5 Approaches for implementation of AIoT for sustainable water facilities

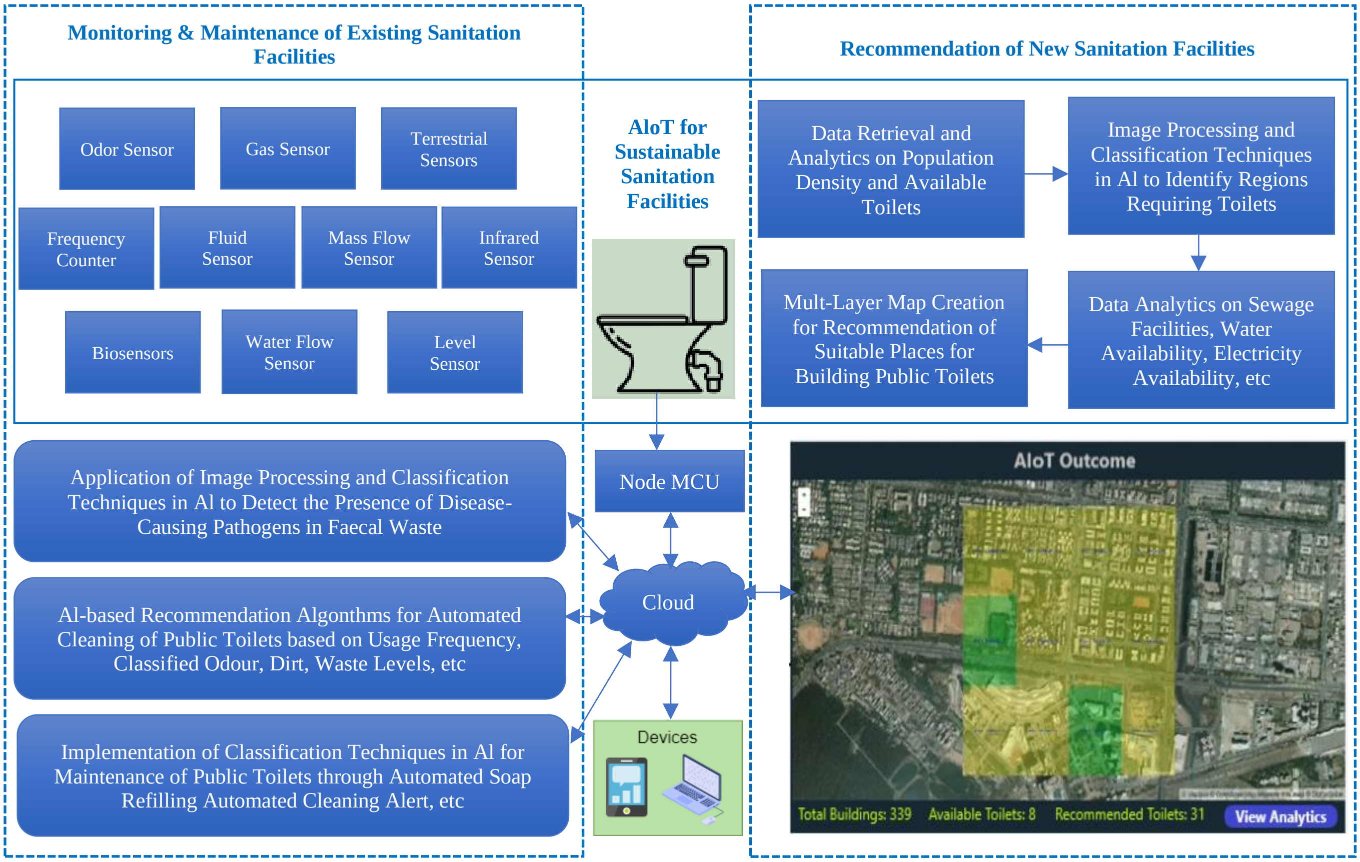

Fig. 6 Approaches for implementation of AIoT for sustainable sanitation facilities

4.2. AIoT for Sustainable Sanitation Facilities for Public

AIoT can used to achieve sustainable sanitation facilities for all, especially for women and girls in vulnerable situations. Particularly, AIoT can be utilized to monitor the condition of existing sanitation facilities and recommend installing new sanitation facilities wherever unavailable. Further, through AIoT, recommendations of locations for constructing toilets can be provided using data such as population density, present number of toilets, water availability, sewage facilities, etc. A detailed approach for the same is described below and presented in Fig. 6.

AIoT can play a crucial role in ensuring the cleanliness of sanitation facilities. By combining AI with IoT technologies, smart systems can be created that monitor and manage sanitation facilities efficiently. AI models trained on sensor data can predict sanitation-related user behaviour and environmental events to mitigate threats to public health due to poor sanitation management. By utilizing data from terrestrial sensors in sewage systems, biosensors, etc., predictive models with Image Processing and Machine Learning can be trained to detect the presence of pathogens in excreta and predict potential disease outbreaks. The AIoT systems can replace manual approaches for testing diseases in sewage, thus eliminating health and economic issues.

Installing IoT-enabled sensors in sanitation facilities can provide real-time data on factors like usage frequency, classified odour, dirt, waste levels, etc. The data can be utilized to trigger automated recommendations for cleaning processes or alert cleaning staff when maintenance is required. Implementing classification techniques in AI on sensor data collected from sanitation facilities to identify patterns and predict maintenance needs such as automated soap refilling. In advance, maintenance can be scheduled proactively by detecting potential issues, such as clogged drains or malfunctioning toilets, minimizing downtime and ensuring continuous cleanliness.

Along with maintaining existing facilities, AIoT can also be applied to establish new facilities. Fig. 6 depicts an approach for recommending new sanitation facilities, specifically public toilets. The first phase performs data retrieval and analysis on the population density and existing /available number of toilets for each area under consideration.

The second phase uses Image Processing techniques and classification techniques in AI to identify regions where toilets are required. The next phase consists of applying data analytics on parameters such as sewage facilities, water availability, traffic conditions, electricity availability, the existence of nearby bus stands/railway stations/markets, etc., for the regions identified in the second phase. Finally, a multi-layer map is built, marking empty spaces for developing new public toilets.

These research directions can be implemented to end open defecation and assure access to adequate and equitable sanitation for all at appropriate locations, with maximum utilization.

4.3. AIoT for Sustainable Hygiene Practices for Public

The need for AI in sustainable hygiene practices arises from the fact that AI can process large amounts of data generated through IoT devices in real time and generate insights to improve hygiene practices for the public. Several research directions for the same are depicted in Fig. 7.

One of the major indicators of hygiene is the air quality. Temperature, availability of ventilation, vehicular traffic, dirt, emissions of harmful elements, etc., are the major factors affecting indoor and outdoor air quality, especially in populated regions. Specialized Particulate Matter (PM) sensors measure dust particles under 2.5 µm, CO2, moisture level, etc. Photoionization Detector (PID) measures Volatile Organic Compounds (VOCs) like benzene and other gases. Nitrogen Dioxide (NO2) sensors measure NO2, a gaseous air pollutant formed due to fuel burning. Similarly, other specific sensors, like ozone sensors, ammonia sensors, etc., provide air quality measures.

Data from these sensors can be processed using AI to monitor air quality, discover sources of air pollution, forecast air quality, and execute remedial actions in real time. To prevent the spread of infections, hand hygiene is a foremost requirement. The emergence of the COVID-19 pandemic has increased awareness of hand hygiene, which can be further stimulated using AIoT. IoT sensors can be placed on soap dispensers, hand sanitizer dispensers, and handwashing stations to monitor their usage in real-time at public places, schools, etc.

AI can analyze data from these IoT sensors to predict when hand hygiene products need to be refilled or when dispensers need servicing. AIoT-based wearable devices can provide real-time feedback to individuals to encourage proper hand hygiene practices and send automated reminders to healthcare workers, patients, and visitors to wash their hands regularly, especially before and after patient contact. AIoT can be used for contact tracing in times of outbreaks, identifying areas that require additional cleaning and disinfection, and individuals needing pre-emptive hygiene actions.

AIoT can play a crucial role in reducing foodborne illnesses and ensuring the overall quality and safety of the food supply chain by analyzing and learning from different parameters. Data Analytics from temperature sensors can ensure that perishable foods are stored at the correct temperature, humidity sensors can monitor moisture levels, and pH sensors can detect spoilage.

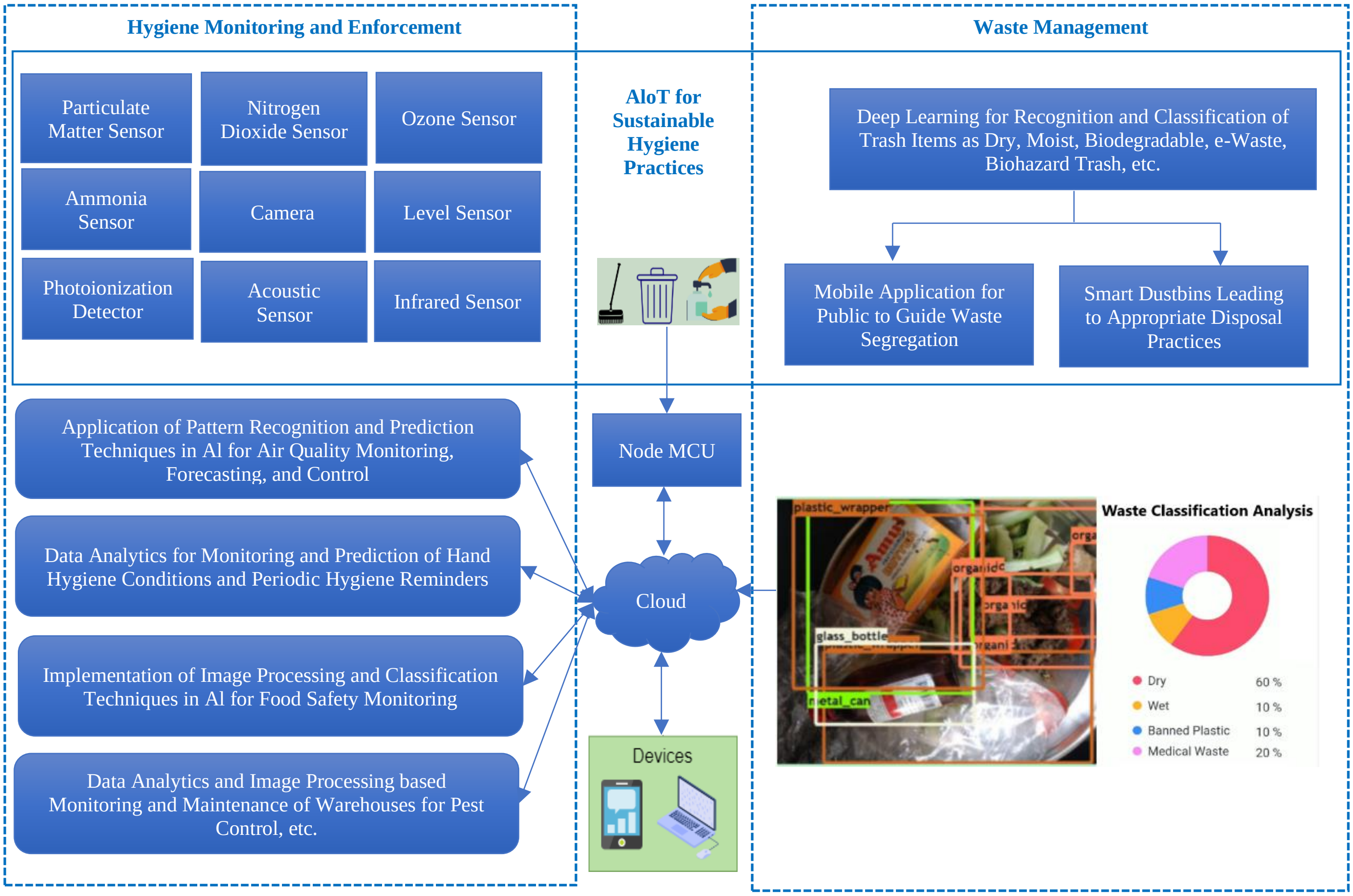

Fig. 7 Approaches for implementation of AIoT for sustainable hygiene practices

On detecting and classifying potential food safety issues, automated alerts can be sent to relevant stakeholders, such as food producers, distributors, or regulators, via Mobile Applications to enable prompt action. By integrating AIoT with food traceability systems, it becomes easier to track the source and movement of food products through the supply chain. In food safety issues, AI can be employed to identify the affected batches and support the recall process, thus minimizing the impact on public health.

Leveraging AI and IoT technologies can aid pest control professionals in making data-driven decisions. The collected data and analysis can provide valuable insights into pest behaviour, identify trends, and help optimize pest control strategies. IoT devices can be strategically placed in areas prone to infestation, such as storage areas, entry points, and food preparation zones. Image Processing and Data Analytics can be applied to the data retrieved from these IoT devices to distinguish between pests and other objects and detect anomalies that indicate a pest infestation. By combining historical data on pest activities with real-time sensor data, AI can develop predictive models to forecast potential pest outbreaks or infestation risks. These models can help identify vulnerable areas, highlight factors contributing to infestations (such as food sources or environmental conditions), and enable proactive measures to prevent pests from entering or spreading within the premises.

Waste management can be automated and improved with AIoT solutions. Overflowing waste bins can compromise hygiene and require proper disposal practices. A major challenge is solid waste management, which involves classifying trash items as dry, moist, biodegradable, e-waste, biohazard trash, etc. Without an automated system, the cleanliness workers must manually segregate the trash, making them vulnerable to health issues. As shown in Fig. 7, an AIoT system can accurately identify objects in the trash and further apply Deep Learning on real trash images captured from residential societies, hospitals, public places, etc., to learn the trash classifications. The nation's citizens can use a recommendation system based on these classifications through a mobile application to segregate the trash at their houses/public premises and dispose of it accordingly. Smart dustbins with the ability to analyze trash segmentation can be used by society authorities / municipal organizations to assess households/localities for their waste segregation practices, thus assuring the implementation of solid waste management norms.

5. Conclusion and Future Scope

The work applies Data Analytics on the WASH indicators to identify the population lacking access to necessary and sufficient Water, Sanitation, and Hygiene facilities. Further, the work presents research directions to implement AIoT to identify patterns that indicate potential failures, requirement of maintenance, early warnings about water contamination, etc., by leveraging classification, regression, etc. techniques on real-time data collected from IoT sensors. Furthermore, the work discusses the approaches for using AIoT to monitor the functionality and usage of sanitation utilities, facilitate predictive maintenance of sanitation infrastructure, recommend new facilities such as toilets at suitable locations, etc. Finally, the work identifies methods to apply AI algorithms on real-time data from IoT-enabled devices to monitor and enforce air hygiene, food, warehouses, etc., as well as apply Deep Learning for effective waste management and disposal through smart dustbins.

Implementing the research directions identified in the work and the extension of AIoT for achieving universal access to WASH conditions, particularly for vulnerable populations such as children, women, and communities affected by humanitarian crises, remain avenues for future scope.

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References

[1] Guy Hutton, and Claire Chase, *Water Supply, Sanitation, and Hygiene*, Injury Prevention and Environmental Health, 3rd Ed., The International Bank for Reconstruction and Development/The World Bank, 2017. [Google Scholar] [Publisher Link]

[2] Global Water, Sanitation, & Hygiene (WASH), Centers for Disease Control and Prevention. [Online]. Available: https://www.cdc.gov/healthywater/global/index.html

[3] Florence Dery et al., "Understanding Empowerment in Water, Sanitation, and Hygiene (WASH): A Scoping Review," *Journal of Water, Sanitation and Hygiene for Development*, vol. 10, no. 1, pp. 5-15, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[4] Department of Economic and Social Affairs Sustainable Development, United Nations. [Online]. Available: https://sdgs.un.org/goals

[5] Emily Ying Yang Chan et al., "Narrative Review of Primary Preventive Interventions against Water-Borne Diseases: Scientific Evidence of Health-EDRM in Contexts with Inadequate Safe Drinking Water," *International Journal of Environmental Research and Public Health*, vol. 18, no. 23, pp. 1-20, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[6] P. Durgaprasad, and P. Sivaram, "Good Governance and HRD: Case Studies of User Managed Safe Drinking Water and Health Projects in India," *Asia Pacific Journal of Rural Development*, vol. 17, no. 1, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[7] Bernardo Aleixo et al., "Infrastructure is a Necessary but Insufficient Condition to Eliminate Inequalities in Access to Water: Research of a Rural Community Intervention in Northeast Brazil," *Science of the Total Environment*, vol. 652, pp. 1445-1455, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[8] Edilberto Nunes de Moura, and Mario Procopiuck, "GIS-Based Spatial Analysis: Basic Sanitation Services in Parana State, Southern Brazil," *Environmental Monitoring and Assessment*, vol. 192, no. 2, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[9] Ankita Pran Dadhich, Pran N. Dadhich, and Rohit Goyal, "Synthesis of Water, Sanitation, and Hygiene (WaSH) Spatial Pattern in Rural INDIA: An Integrated Interpretation of WaSH Practices," *Environmental Science and Pollution Research*, vol. 29, no. 57, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[10] Pedi Obani, and Joyeeta Gupta, *Chapter 12 Human Security and Access to Water, Sanitation, and Hygiene: Exploring the Drivers and Nexus*, Handbook on Water Security, pp. 201-214, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[11] Demetrios E. Tsesmelis et al., "Water, Sanitation and Hygiene (WASH) Index: Development and Application to Measure WASH Service Levels in European Humanitarian Camps," *Water Resources Management*, vol. 34, pp. 2449-2470, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] The WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) has Reported Country, Regional and Global Estimates of Progress on Drinking Water, Sanitation and Hygiene (WASH) Since 1990, WHO/UNICEF Joint Monitoring Programme. [Online]. Available: https://washdata.org/

[13] Tien-Wen Sung et al., "Artificial Intelligence of Things (AIoT) Technologies and Applications," *Wireless Communications and Mobile Computing*, vol. 2021, pp. 1-2, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[14] Biju Bajracharya, and Vamsi Gondi, "Prospects of AI Enabled IoT," *International Journal of Computer Trends and Technology*, vol. 68, no. 9, pp. 11-16, 2020. [CrossRef] [Publisher Link]

[15] Ian Goodfellow, Yoshua Bengio, and Aaron Courville, *Deep Learning*, MIT Press, 2016. [Google Scholar] [Publisher Link]

[16] Elaine Rich, Kevin Knight, and Shivashankar B. Nair, *Artificial Intelligence*, 3rd Ed., Tata McGraw-Hill Publishing Company, pp. 1-478, 2009. [Google Scholar] [Publisher Link]

[17] Samuel Greengard, *The Internet of Things*, The MIT Press, 2021. [Google Scholar] [Publisher Link]

[18] Maciej Kranz, *Building the Internet of Things*, John Wiley & Sons, 2017. [Google Scholar] [Publisher Link]
[19] Amir Hamzeh Haghiabi, Ali Heidar Nasrolahi, and Abbas Parsaie, "Water Quality Prediction Using Machine Learning Methods," *Water Quality Research Journal*, vol. 53, no. 1, pp. 1-11, 2018. [CrossRef] [Google Scholar] [Publisher Link]
[20] Klaus Schwab, *The Fourth Industrial Revolution*, Crown Business, 2017. [Google Scholar] [Publisher Link]
[21] Ashish Ghosh, Debasrita Chakraborty, and Anwesha Law, "Artificial Intelligence in Internet of Things," *CAAI Transactions on Intelligence Technology*, vol. 3, no. 4, pp. 208-218, 2018. [CrossRef] [Google Scholar] [Publisher Link]
[22] Richa Umesh Shah et al., *AIoT Technologies and Applications for Smart Environments*, Institution of Engineering and Technology, 2022. [CrossRef] [Publisher Link]