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A review on smart water management in various domestic areas: an approach for water consumption and leakage perspectives

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Abstract: One of the major issues that is affecting the water utilities in domestic areas is leakages through the distribution networks, non-revenue water estimation, and failure in the prediction of water consumption at individual spaces. This review paper basically focuses on these three important directions to understand the feasible domestic water management systems with integrated models of internet of things and artificial intelligence approaches. Different smart water management techniques have been reported in the literature to improve efficiency and avoid non-revenue water issues, and these are consolidated in this paper. Prediction failure of water utility in the water distribution systems is also presented in this paper. This article summarises a measure of water consumption statistics, a detailed summary of non-revenue water, and leak detection technologies at extensive areas to provide a wide sense of understanding for the prediction of the water consumption and leakage detection.

Keywords: smart water management; leakages; non-revenue water; NREW; district metered area; DMA; artificial intelligence; domestic areas; water consumption; distribution networks; non-revenue; detection.

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1 Introduction

According to the population division of the United Nations, half of the world residents are living in the metropolitan cities by 2018 and this will be improved due to various factors (Popfacts, 2018). This fast-growing of urbanisation may affect the water services in unplanned cities and the developing nations like India. Most of the Indian cities are having intermittent drinking water supply with once in two days to once in a week (Rao et al., 2015). These water distribution networks (WDN) have experienced deteriorating infrastructure and water losses due to period of establishment, and damages. This results in technical, financial, and economical problems (Selim et al., 2018). Hence, the decision process for a restoring policy needs to be positioned to make sure that each water distribution system (WDS) remains to work efficiently also cost-effectively within the definite working necessities above an extended period to assemble present and upcoming demands form a major area of interest (Engelhardt et al., 2000; Kloosterman and Van Der Hoek, 2020).

It is necessary to work extensively on the analysis of water losses which leads to non-revenue water (NREW) includes bodily leaks and profitable losses of WDN because moving towards dynamic approaches that achieve long term cost-effective efficient systems (Jang et al., 2019). As stated by Kingdom et al. (2006), NREW is the most necessary situation that distressing water utilities in the present-day state and the widespread dissimilarity among the quantity of water distribution in the transport devices and additionally every volume regarding water charged on users. High degrees about NREW expose considerable amounts like water holding long past off beam via leaks, now not being invoiced to clients. This situation badly harms the monetary opportunity of water utilities via wasted revenues and higher operational expenses. An excessive NREW degree is commonly an alternate to any weakly moved water service that needs special authority, liability, including as a result of some technical plus decision-making competencies critical to grant unfailing providers over their community. Lambert (2002) explained the global water association (IWA) venture drives at water wastes plus enforcement actions, including better theories during modelling machinery from leakage plus stress. The IWA project force tips give unpaid explanations also paths on several issues that ought prompted steady issues during quantifying water wastes also contrasting effectiveness from their supervision.

Similarly, a meaningful and general method of Gomes et al. (2015) given the renowned best practices in the route of scale returned water losses incorporate

1 pressure running

2 dynamic leakage limitation

3 rate, and a class about improvements

4 asset supervision.

Water waste administration can end up a pretty composite in outsized WDN, and in these bags, the functioning of district metered areas (DMAs) is necessary to get first-rate results. Alvisi and Franchini (2014) briefed in relation to DMAs, these district metering techniques improve the WDS administration and smaller portions of these are known as DMAs. These DMAs are positioned at stop separation valves along with pipes linking to diverse factors and inserting a waft metre in the final linking channels to hold the quantity of inflow including an outpouring of every DMA. It is viable to toil out the water balance of the DMA and look at least darkish flows, as a consequence acquiring data that is useful for figuring out the existence of leakage in the district. Furthermore, the required data acquired at the DMA level is regularly utilised in the viewpoint of concurrent structure managing. Lobbrecht and Solomatine (2002) expound the real-time manage (RTC) regarding water operations must turn into a greater line to absolutely use the accessible ability of any water system. RTC has utilised to manage structures in metropolitan and rural waterways, which can cast off the want for fundamental savings in water-systems infrastructure. While some latest traits, RTC becomes forthwith grown to be vital for total water administration, not simply a fascinating low-cost measure. RTC assures a shut healthy of water-system explains by some time-varying necessities of water practices. Correspondingly, nowadays digital water metres (DWM), accompanied via ML statistic analytic DA procedures, can perform essential tasks by using supplying regular and instant statistics for recognising also executing profitable water demand approaches (Rahim et al., 2020). This paper starts with an introduction to the water management system, issues with the urbanisation, and various studies on the smart water management system. The methodology section explains the literature review of four different directions. The paper concludes with summary as well as future perspectives about the smart water management system.

2 Methodology

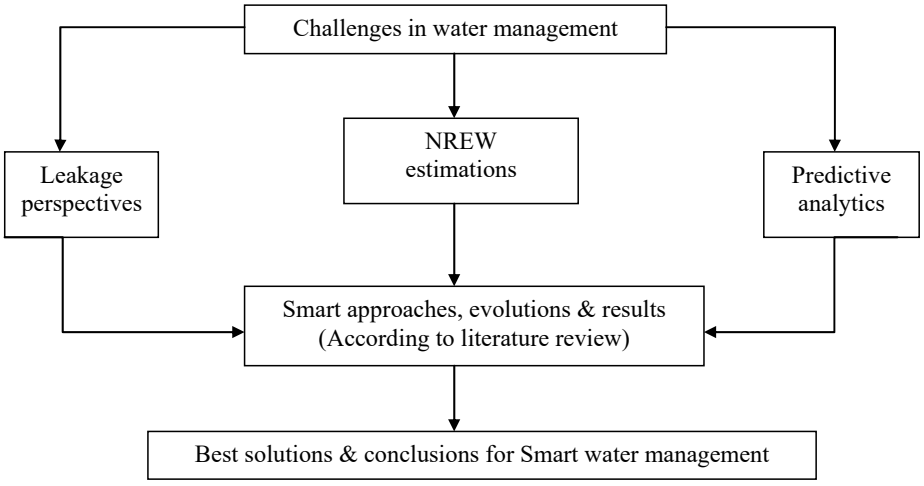
The combined methodology described in this review contribution is having four distinct ways. These ways focuses on approach, evaluation, and result analysis of available international peer-reviewed literature. The subsections of this include leakage detection, NREW estimation, the prediction analysis due to the wide range of the smart water management topic, and finally focuses on an integrated IOT and artificial intelligence models for smart water management system.

2.1 Literature review approach

Generally domestic water networks are transmitting water through the underground pipeline system. There is a 20% to 30% of water wastage in these systems and it may be more at old systems. There are several reasons for water waste in the water management operation which comprises leakages, theft, and metering blunders (Hunaidi, 2000;

El-Abbasy et al., 2016). This review ambition is to discover the smart options handy in the peer-reviewed literature and the proposed evaluation method of this paper is summarised in Figure 1.

Figure 1 Proposed literature survey methodology



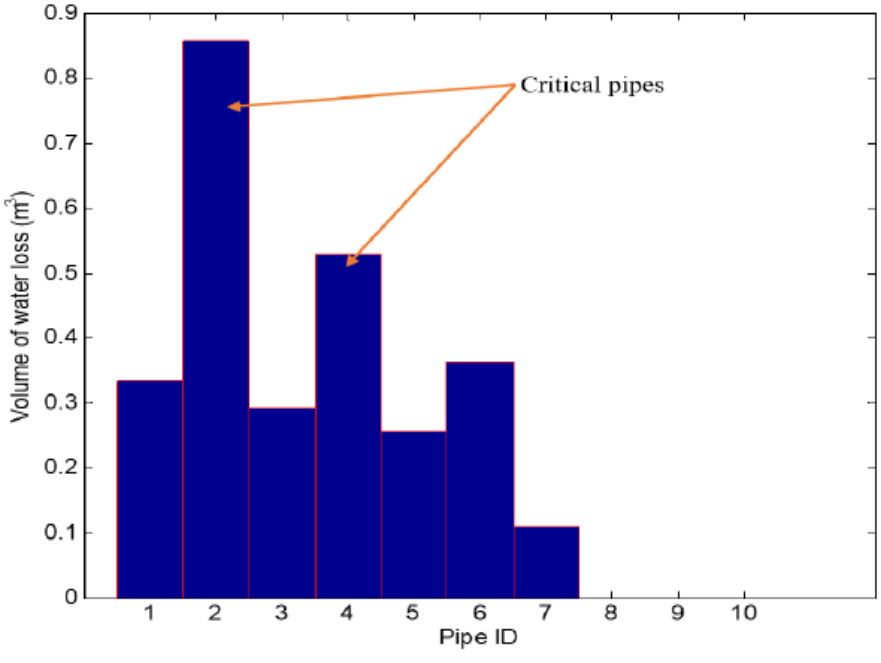
2.2 Leakage perspectives: first literature review approach

The losses and dents originated through the leaks entailed new methods and procedures to decrease their quiet impact. As a conclusion result, some researchers throughout the globe contributed their struggles to that progress of a full-size vary of procedures to leak recognition, leak position, plus keep away from water losses. This existing session carries a summary of the leakage views presented in the literature and tabulated as proven in Table 1. Anand et al. (2019) created some water regulation monitoring gadget that affords uninterrupted water waft monitoring, managing, and leakage detection inside channels. In this lookup contribution, float metres are installed at various links to read the readings of water regulation. These readings will be dispatched to microcontroller and Wi-Fi/LAN module denotes practiced to save these readings on Firebase cloud. Mobile app interfaces by cloud and can provide users get right of entry to their usage information in a graphical form. A person of every apartment is given login credentials to view their monthly/weekly/daily usage, estimated cost, etc. Users can be notified when utilisation exceeds every range, and leakage can be recognised by comparing the readings of flow metres on the same line of pipe connection. Adedeji et al. (2017) provided a set of guidelines for figuring out and assessing backdrop leakage in WDN. The algorithm merges one leakage replica toward an ordinary WDN hydraulic model for fixing the machine leakage flows. The hydraulic evaluation is done via modelling the water system topology and solving the resulting model by way of an iterative Newton-based methodology.

The algorithm combines some leakage reproduction into a standard WDN hydraulic method for fixing the device leakage flows. This application of the improved algorithm does validate two varied water networks. An important confirmation is that the algorithm lets in the consciousness of significant segments or pipes of the machine experiencing

excessive leakage discharge and shows the viable pipes of the device where strain administration is often performed. All through some hydraulic examination of that method, the nodal leakage flow occurs calculated plus the algorithm then exams if the approximate leakage outflow at the joint is enormously low, and if before-mentioned is confirmed, it states no leaking joint while some run price in such joint is much less than forbearance rather comparatively cheap. Unless it reaches that leaking joint wide variety and searches for all the pipes related to this joint. Subsequently, it computes the leakage drift in every pipe. Additionally, it exams if the approximate leakage goes with the flow in every pipe is exceedingly high. So the channel is marked essentially crucial pipes as shown in Figure 2, then algorithm recommends stress manipulate alongside the necessary pipes.

Figure 2 Water loss quantity in every pipe for the case swot system (see online version for colours)



Source: Adedeji et al. (2017)

To set up an appropriate DMA system is considered the use or alteration of the myth developed through Gomes et al. (2015) is primarily based on diagram concept ideas and some user-defined standards to create the wide variety and dimension of DMAs and uses a computer-generated algorithm to mark the most immense figure and function of metering locations, aspect pipes, and device again up the replacement. So the role of DMA management is separated into Rao et al. (2015) procedure into convenient areas or sectors into which the flow can be calculated to establish whether bursts are there. The purpose of this is to intend WDS to carry potable water more spatially widespread areas in mandatory quantities and under acceptable pressures using inherent and explicit constraints as well as hydraulic zoning of DMA's (AlAbdulkarim and Lukszo, 2010).

Table 1 list of leakage and water losses methods

Reference	*Methodology*		*Result*
	Approach	*Evaluation*	
El-Zahab and Zayed (2019)	Leakage identification into pipelines	The two modules of leak recognition systems are acknowledged by inactive leak recognition methods and active waste recognition methods.	Inactive drop recognition methods give quick loss recognition with the least personal intervention. On another pass, active loss recognition methods are practiced to prove the presence of leaks by assembling strategy plus group on so-called regions.
Anand et al. (2019)	Water leakage alerts and monitors in the home	A water flow sensor with microcontroller and servomotor which will use as a switch gate. And a fire based cloud for connecting backend cloud. The servo motor is used to control water flow is used to measure the water level.	An online application that monitors and pedals the water flow from end to end taps whenever there is an odd reading of the water usage at residence.
Lambert (2002)	NREW and Water Losses.	Noticeable losses should differentiate between systems with and without roof tanks.	This paper summarises with different parameters to get rid of water losses.
Di Nardo et al. (2017)	Identification and reduction of water losses.	DMA's financial and get-up-and-go criteria for multi-objective optimisation.	A valuable tool for a water utility to prefer the optimal water system partitioning
Adedeji et al. (2017)	WDN pressure-driven form toward resolving some system leakage flows.	The procedure entails the hydraulic examination of the water system and the leakage calculation.	This algorithm combines a leakage representation into a WDN pressure-driven standard for resolving the system leakage issue.
Gomes et al. (2015)	DMA design, Floyd-Warshall algorithm, computer-generated Annealing	A graph theory concepts including toward any user-defined models to set up the amount plus range from DMAs and does a computer-generated algorithm to recognise some common suitable figure including the position of metering locations, edge flaps, including system replacement desires all along through the development plan.	During this case swot, the financial advantages are linked to the alteration from that service demand at the DMAs entry points, and those system reinforcements and obtain a result from some water waste drop arises of the medium pressure lowering.
Rao et al. 2015	Municipal water distribution systems	Calibration of implicit constraints, explicit constraints, district metered area	The calibrated WDN furthermore helps in the healthier understanding of leakages in the system.

Table 2 List of non-revenue water estimation methods

Reference	*Methodology*		*Result*
	Approach	*Evaluation*	
Jang et al. (2019)	Estimation of NREW in water distribution networks.	By arithmetical study, procedures such as ANN and PCA.	NREW was approximated after choosing some portions with MRA toward some predictable PCA-ANN method.
Liemberger and Wyatt (2019)	Some quantity of water wasted by water utilities about the world.	Level of NREW, cost and charge of NREW.	Novel examination of universal levels about NREW reveals that some present approximated amount does faraway elevated than before estimated.
Jang et al. (2018)	Estimation of NREW using main parameters of water distribution systems	Calculation of NREW using ANN in the comparison of existing probability	This study applies for the major parameters of WDS to ANN
Jang and Choi (2018)	NREW degree in WDN	An ANN be used to approximate some NREW proportion to advance evaluation accuracy	Estimation of the NREW proportion by an ANN plus MRA was handled by exact parameters altering some regularity like losses in WDS.
Yazid et al. (2017)	NREW in Management, and Infrastructure.	Malaysia NREW Performance	The volume of apparent or commercial losses and their sub-components comprised of unauthorised consumption, metre inaccuracies, and data handling were identified.
Wyatt and Alshafey (2012)	A financial model for optimal NREW to the Aqaba Water Company.	The modified design held related to figure out the 'water balance' plus best NREW, and Comparing definite conditions to the finest conditions.	The significance, payback, and outlay of NREW reduction, forming the root of a determined plan to improve assess and cut lacks near Aqaba City furthermore recited the design in separate areas within its examine province .
Kingdom et al. (2006)	Real losses or apparent losses, and unbilled authorised usage.	Quantifying some apparatus of NREW	This document was equipped as an element to examine possibilities during the utilise of the own sector to help out water utilities in emerging nations in falling NREW.

2.3 Non-revenue water: Second literature review approach

This is indispensable to manipulate losses in WDS via forwarding water technologies. In direct to reduce the water loss, analyses on some primary portions of the water channel gadget concerning NREW is dynamically carried out by Jang et al. (2018, 2019) estimates NREW the usage of arithmetical evaluation strategies such as ANN and PCA, and on figuring out factors that have an effect on NREW in the target place is actively ongoing. Jang and Choi (2018) provided the computation of NREW on the hypothetical background.

$$NREW = \frac{N_p - N_b}{N_p} \tag{1}$$

where *Np* means the quantity of water delivered by point unit and *Nb* means the quantity of billed water by point unit. It also provides the line during determining the NRW ratio utilising MRA and ANN. Liemberger and Wyatt (2019) provided an extended past due to an update on the universal NREW estimates by the level of NREW and calculating the charge/price of NREW.

2.4 Prediction analytics: third literature review approach

Rahim et al. (2020) recognised huge research hollows toward provisions from some selection about sophisticated ML plus DA techniques, which may probably guide to water investments also well-organised call supervision and their assistance and obstacles of ML plus DA methods via appreciably analysed into five core themes:

1 water need forecasting

2 socio-economic testing

3 performance outline

4 water match classification

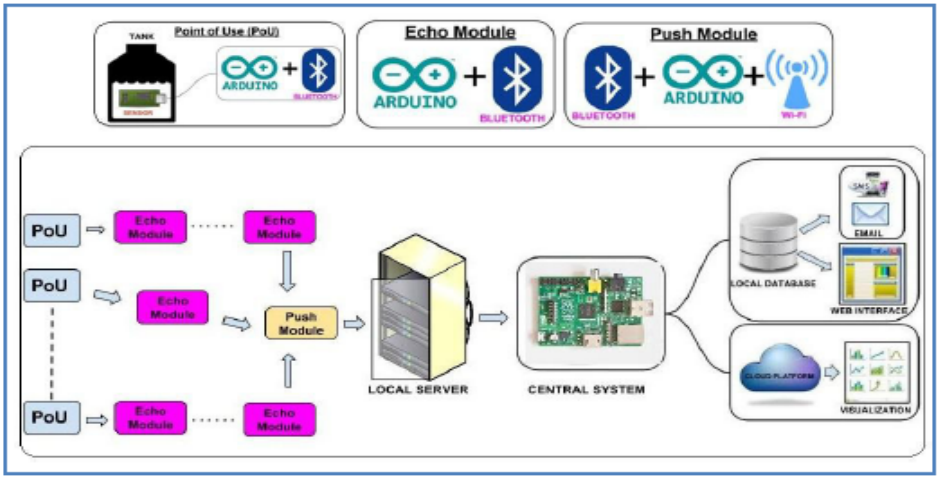
5 water usage response.

Badari Nath et al. (2019) used a Node MCU Wi-Fi unit to achieve wireless communication. An HC-SR04 ultrasonic ranging aspect is used to spot some water levels and automate that pump-action while bringing collectively by DS18B20 water-resistant heat sensor scrutinies over word anomalies in water influx and shut off the water present on the rivalry of undesirable water features. Some statistics provided using the shape is processed by using optimised ML and neural network methods to supply good-sized analytics toward users. In similar to Rahim et al. (2020) close by is one more way to find water demand forecasting using Benítez et al. (2019) pattern similarity-based techniques using data locations like the built-up site, downtown site, suburban site, and their records pre-processing.

Herrera et al. (2017) defined the bendy computing apparatus to rightfully deal with the significant amount of data generated with the aid of methods connected to smart water applications. To manipulate the massive extent of facts that does concoct these days using water services remains a new promising mechanism that justifies additional enlargement and research. Helmbrecht et al. (2017) make utilise of energetic statistics plus transforms them toward positive statistics to hold up choice making. Some smart metering also, for this reason, the use of a huge amount of facts from a device enhances every operation of software program for evaluation support; however, it's not a single way. These Resolutions can further be used for systems with much less recorded data, which might make bigger operators' familiarity with these data, go round them into beneficial statistics for decision-making also for the process or the protection as properly as machine design. The stage affords guide and offers suggestions to the network administrators to enhance choice making, the use of real-time records and some create operational situations in a pleasant graphical background. Shahanas and Sivakumar (2016) projected the IoT system to formulate specific usage of Raspberry Pi and Arduino

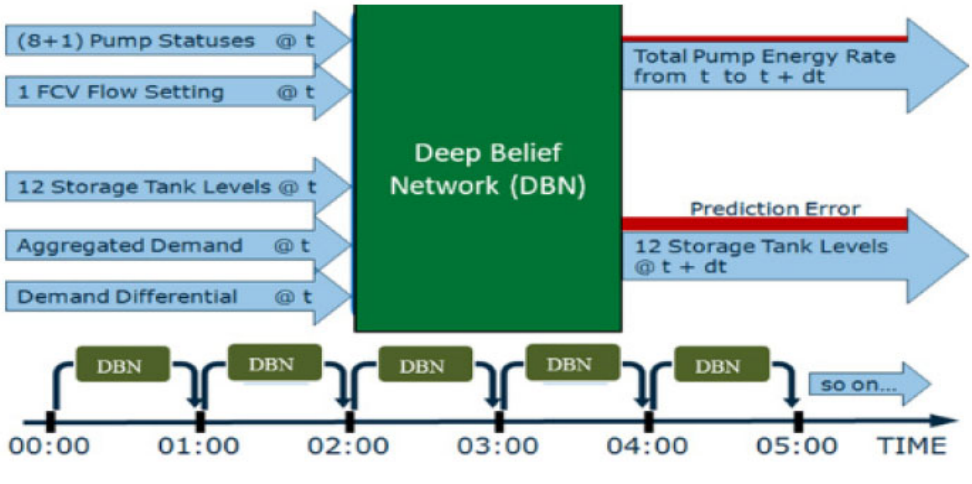
utilised to data collection. The shape consists of point of use, resonance module, data dealing out, and addition. Point of Use (PoU) are the areas wherever water level sensors should be located, the PoUs may well either would possibly no longer be in the range of Wi-Fi. An Arduino board with Bluetooth approves can be applied as a resonance module. Finally fill some data into matching records during visualisation, patch up these statistics to the cloud, activate e-mail warning during the water stage goes beneath the threshold, trigger e-mail with distinctive reviews on a daily/monthly/yearly basis as depicted in Figure 3.

Figure 3 A smart water executive system (see online version for colours)



Source: Shahanas and Sivakumar (2016)

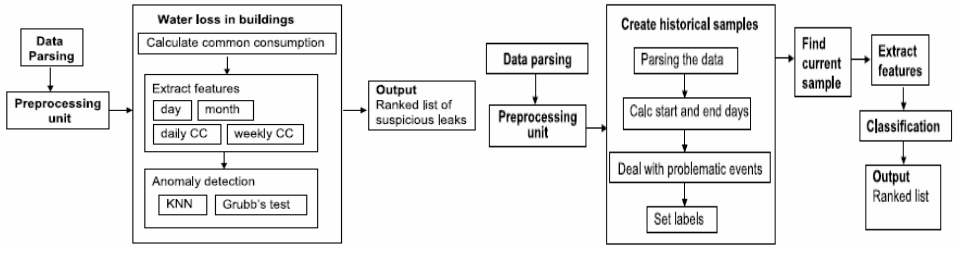
Figure 4 Arrangement of deep learning representation structure for simulation of a WDS (see online version for colours)



Source: Wu et al. (2015)

Wu et al. (2015) elaborated the growth of proficient deep learning to know structure with possible applications of putting collectively viable of accessible records fusion, device replication also predictive examination, awareness of irregular events as of the recorded point collection of water handling prediction and the characteristic of deep belief network is proven in Figure 4. Kermany et al. (2013) current their run-through of the usage of ML techniques above information created from superior metre infrastructure (AMI) the automatic detection of faulty measures by some focus at differentiating them of rational non-use before-mentioned as for some duration of when the household residents are about left. The different use case is that focus from leaks either theft under the unmetred extensive areas of condominium structures as proven in Figure 5. Lobbrecht and Solomatine (2002) presents the application of ML techniques is projected, the use of ANN plus FAS. Results acquired within a good sample revise note that these qualified controllers, can repeat centralised management performance rather precisely also quickly while applying solely confined information sources.

Figure 5 Algorithm's method for recognition of losses in familiar areas of buildings and detection of fault metres



Source: Kermany et al. (2013)

Table 3 List of prediction analytics methods

Reference	*Methodology*		*Result*
	Approach	*Evaluation*	
Rahim et al. (2020)	Data analytics; digital metering data; machine learning.	The contributions of ML and DA are categorised into five major themes: water demand forecasting, socioeconomic examination, performance analysis, water event classification, water-use response.	A satisfactory amount about ML and DA strategies possess continued useful to the records obtained from DWMs.
Badari Nath et al. (2019)	Water consumption prediction and water usage analysis	Node MCU, HC-SR04, DS18B20, firebase, analytics, data aggregation.	Found the leakage and predicting the usage pattern using machine learning
Benítez et al. (2019)	Water demand forecasting	The pattern-based forecasting technique used in this effort is generally applied	A precise predict of point in time series relies deeply on the steadiness of the signals.

Table 3 List of prediction analytics methods (continued)

Reference	*Methodology*		*Result*
	Approach	*Evaluation*	
Herrera et al. (2017)	Data analysis of smart water networks	Soft computing techniques for WDS management and operation and management of smart water networks	Soft com-putting intended for the smarter process running in WDS.
Helmbrecht et al. (2017)	Energy managing within WDS.	By records acquirement and geographical visualisation, local weather and water need forecasting, awareness of systems measures also at some point of a choice aid machine primarily based on gaining knowledge.	AI strategies aid to switch the professional managers' understanding and are bendy to permit significant enhancement from particular equipped techniques above time, serving into the non-stop development from the administration strategies.
Shahanas and Sivakumar (2016)	Duration of using echo module for data processing and integration	Sensors remain located in PoUs. Every PoUs holds four sensors at assorted levels. Sensors will provide any true, if the water continues beyond to that point others go back wrong. The unit Arduino board is positioned during each PoUs. Arduino board does configure to confine specific data of sensors.	Deep learning about rising technology, the IoT, and Predictive Analytics does make also its value in the frame of smart city.
Wu et al. (2015)	Data analytics, data-driven model, deep learning	Deep gaining knowledge of structures can robotically take out the points by way of training the shape by unlabelled data, and then use certain automatically selected facets to categorise that picture the use of a trainable classifier.	This study task is aiming to increase a common, robust, valuable, and proficient data-driven examination device via the use of a composite computing paradigm.
Kermany et al. (2013)	Recognition of not working metres, and detection of leakages or robbery while some unmetered common sections from residential constructions.	Study of AMI data generates at apartment buildings.	A novel data-mining function that holds great assure for tackling issues of major significance to the process of municipal water supply.

Table 3 List of prediction analytics methods (continued)

Reference	*Methodology*		*Result*
	Approach	*Evaluation*	
Lobbrecht and Solomatine (2002)	Major dynamic control troubles through intellectual control.	The function of the ML theme does propose, applying ANN and FAS.	To restore a centralised management shape for a water machine through adaptive designs that utilise solely nearby records and work regionally to manipulate any individual modifiable arrangement.
Engelhardt et al. (2000)	Restoring, verdict models, WDN	Levels of examine, compulsory leakage targets, water class, serviceability.	It has been acknowledged that a decision model must add in financial, hydraulic, consistency, and water class criteria. Frequent measures and models have been reported in the prose.

2.5 An integrated IOT and ML model for smart water management: fourth literature review approach

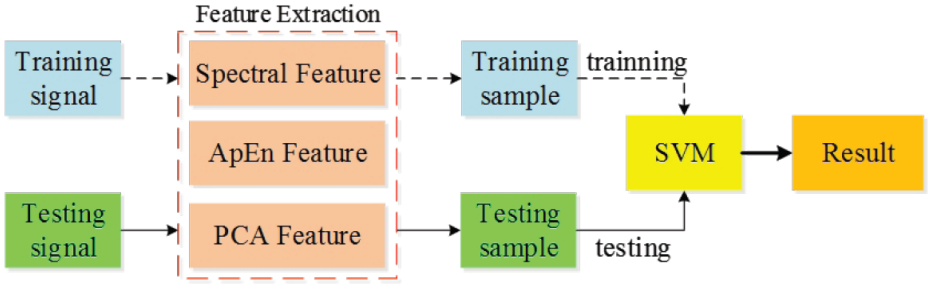
Smart water management requires various evolutions to reach the challenges of rapid urbanisation. This requires replacement of all conventional water monitoring and management systems with IOT enabled digital metres and AI models for the prediction estimation, which leads high efficiency and transparency in the domestic water management system. The key parameters of these models are, measures the outflow of water from the metres, as well as uploads the measured data to the server in every minute of the water flow and predicts the consumption details of that particular metre by using the data available in the server.

In this context, various researchers presented their integrated models for agriculture and domestic applications. Goap et al. (2018) presented a smart structure to calculate the irrigation needs of an area with sensors alike soil precipitation, soil temperature, moreover environmental circumstances all on by the climate estimate facts of the internet. One intellect about those planned machines implies predicated upon a rational algorithm, which counts sensed facts all on by vicinity climate point of view parameters alike rainfall, atmosphere temperature, moisture, including UV towards the next prospect. The machine holds per demand to closed-loop administration from these liquid delivered to apprehend a self-sustaining irrigation scheme. Rojek and Studzinski (2019) explained the thinking of detecting plus locating leakages interior water furnish community with geospatial information system and supervisory control also data acquisition scheme moreover hydraulic model from that water stores way, an algorithm from waste recognition plus vicinity primarily based on the neural networks by way of the capability of multi-layer perception.

Liu et al. (2019) calculated some leakage consciousness techniques based on computer learning and wireless medium sensor networks (WSNs). By insertion of wireless sensors mounted on pipelines on the way to acquire details and execute remote

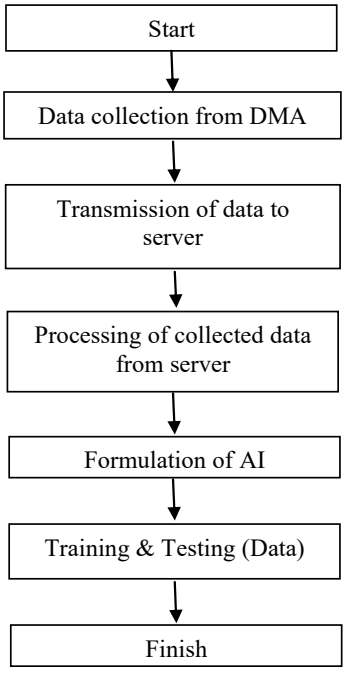
data transmission To enhance that accuracy and Genius of leakage recognition, a leakage attention system that applies the fundamental style use, estimated entropy, also most important element examination to construct some signal attribute set and that uses an aid vector desktop SVM as a classifier to execute leakage recognition. The schematic figure of the SVM recognition model training is given in Figure 6.

Figure 6 Schematic figure of the SVM recognition model training (see online version for colours)



Source: Liu et al. (2019)

Figure 7 Study diagram for a well planned smart water management domestic network



Al-Zubaidi et al. (2019) gives an included professional water managing method used with IoT plus AI algorithms that are applied to build up to hold the addiction of water resources in various applications. Ponraj and Vigneswaran have shown the reason for IoT and ML in agriculture farms supplied with dissimilar ML algorithms and strategies which aid the farmer with insights, essential action, and support. Sun and Scanlon (2019)

examined the changes and benefits of data-driven exploration in environment also water management (EWM). This exemplifies quite massive information as properly as requests to a huge set of massive statistic analytics, from information virtualisation, area computing, low latency statistics broadcast to huge throughput, real-time dispensation. Thus finally given sketches from key theories and procedures in big information and ML with some methodical evaluation from present purposes, and eventually discusses main issues plus challenges, and promote future lookup directions. District metered area, GPRS, LCD hardware equipment, and flow of AI algorithm as shown in Figure 7 is required to achieve a well planned smart water management domestic network.

3 Conclusions

The key point of this review contribution is to summarise the obstacles along with possible solutions for domestic smart water management and take the advantage of integrated IoT and AI models to enhance the WDNs. There are numerous smart solutions are available in the literature to avoid non-revenue water consumption and leakages. These approaches can give a more stable environment than the conventional water networks. Presently many WDNs contain a lack of suitable water metre administration and undergo the consequences of minor levels of returns from water sales. But according to the available literature on leakages, NREW, predictive analysis and smart solutions, it is clear that the current smart technologies are not enough to achieve huge challenges in the urban water management system and requires high predictive analytic models. The future research in WDNs should concentrate on the development and deployment of low cost DWMs for collection of the efficient data, and need to develop the accurate predictive models. Efficient online leakage monitoring systems has to develop, and employ of smart water management to unplanned water networks should improve.

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