Use of Digital Technology to calculate water footprints for different daily use items

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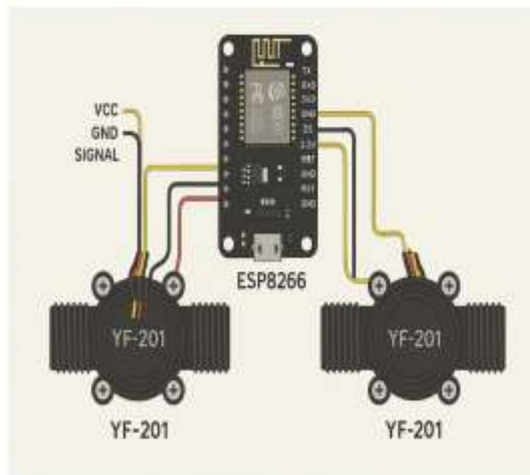
Abstract

Water scarcity is growing day by day in both urban and rural areas of the world, partly due to unmonitored domestic consumption and a lack of real-time usage insights. Traditional meters offer only monthly aggregated readings, hence restricted user awareness and delayed corrective actions. This research proposes a fully functional IoT-based water footprint monitoring system devised to track per-tap water utilization by using dual YF-201 flow sensors integrated with an ESP8266 microcontroller. The system detects flow in real time, which is converted into understandable volumetric flow measures and sent for display on a web dashboard that can be customized. With extensive testing of the prototype, high accuracy, low latency, and user interpretability were observed. Further, this paper describes the motivation, hardware architecture, software implementation, the methodology followed for evaluation, and the possible expansion opportunities toward scaling up the system into a full-fledged household water intelligence platform. This digital solution supports the UN Sustainable Development Goals, specifically SDG 6 and SDG 12, through water conservation and responsible production by way of easy-to-usetechnology.

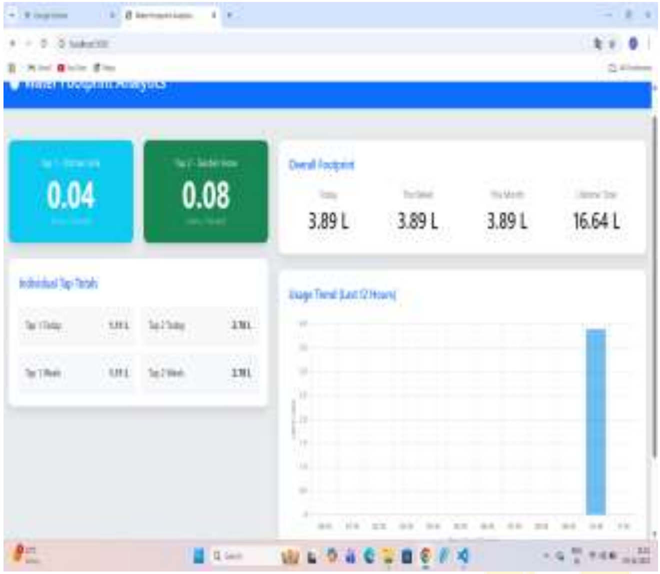
Keywords - IoT, Water Footprint, ESP8266, Flow Sensors, Sustainable Consumption, Digital Technology, Web Application, Data Visualization, Chart.js, Internet of Things, Environmental Awareness.

FIG. 1. SYSTEM ARCHITECTURE AND HARDWARE SETUP



The diagram shows off our hardware interface setup which we did between the ESP8266 microcontroller and two YF-201 Hall effect based water flow sensors. Each sensor has 3 terminals VCC, GND, and SIGNAL and we powered both sensors from the same 5V line which we tied the ground terminals to the ESP8266's ground reference. We put each sensor's signal out to separate GPIO pins on the ESP8266 which in turn enables us to get independent pulse count from each water line. As water goes through the sensor the internal turbine spins which in turn produces a series of electrical pulses that are in proportion to the flow rate; we use the ESP8266's interrupt capable pins to capture these pulses for real time measurement.

FIG. 2. LIVE DASHBOARD INTERFACE DISPLAYING THE SENSOR DATA



The above image shows the main analytics dashboard of the Water Footprint Monitoring System, which displays both real-time and historical data on water usage gathered using two IoT-enabled YF-S201 flow sensors. The interface we have is card based which which present the key operational parameters. At the top we have the current status of two taps which includes the instantaneous flow rate in L/s and total volume that has been accumulated for each source. Also we see a summary of the combined footprint which reports total water use from all sources over different time frames we have daily, weekly, monthly and lifetime uses. Below these numbers we put out a 12 hour usage trend chart which in turn highlights what we are calling out as peak usage times in the late evening and middle of night. To the right hand side also we put out the individual tap reports for the current day which in total give the user a very close look at the which is to say their.

The upper section of the dashboard features two específicos cards that display the present flow rates for Tap 1 and Tap 2 in litres per second (L/s). The cards calculate total cumulative volume drawn from each tap, so users know how much they are consuming per source. More importantly, with usage recorded for each tap, it gives users a sense of what activities—using water in the kitchen, washups, or watering the garden—contribute the most to their household water footprint. Alongside these two cards, users will see a grouped Overall Footprint Summary. This will show the total water usage across four different "time horizons": daily, weekly, monthly and lifetime. Multi-time horizon reporting allows the user to get an idea of their short-term consumption habits (that is, the daily and weekly), while being reminded of their longer-term water usage habits (thus the monthly and lifetime).Overall, this approach helps users to set objectives, understand their progress and identify periods of excessive water consumption.

FIG. 3. LOGIN PAGE OF THE WATER MONITOR SYSTEM.

Above is the login interface of the Water Monitor application which serves as the access point to the analytics dashboard. We have a full screen background which is water themed and includes images of water droplets and footprints which we use to tie in with the concepts of water conservation and ecological footprint analysis. We have a central, very minimal card which includes fields for username and password, also we have a main action button for authentication. The design is clean and to the point which in turn removes any visual distractions and puts the user's focus right on the form for them to log in. This first point of entry gives the user controlled access to the monitoring system which we present to them via simple yet thematically consistent design.

I. INTRODUCTION

Household water use is a hidden issue for the average person even as the rest of the world puts pressure on us to conserve that which is precious. We as users do not notice waste, we do not see our behavioral trends, and we do not identify leaks without real time data. That is to say we have a large gap between what we know we should do and what we actually do. Out of this has come the use of Internet of Things technologies which are great at taking raw environmental data and turning it into information we can use. Home owners gain immediate access to info on their use patterns by connecting low cost sensors to Wi-Fi enabled microcontrollers. To that end this study we present a dual sensor water monitoring system which we developed which is able to report real time per tap use, to send that data out smoothly, and to present it in a very visual and easy to understand format.Water sustainability also requires the use of precise real time monitoring which in turn empowers consumers to aware of and change their daily water use. We see in the introduction of the Internet of Things which has brought forward microcontroller based solutions for home water management. But it is in the interpretation of that data which they truly add value. Also what they do best is to bring to light what was before unknown such as peak use times, accidental over use during cleaning which may be beyond what was planned, or constant faucet run time. Also we see in the home environment variability which includes fluctuating pressure, different pipe sizes, and sensor nonlinearity which in turn requires calibration. Each step of the system development from hardware setup and firmware fine tuning to the final dashboard design will be put through a carefull ,which is to bring to you a stable, accurate and easy to use tool.

II. IMPLEMENTATION

In this way, the implementation phase has turned the Water Footprint Calculator from a conceptual design into a fully functional, web-based application, while it also aimed at a responsive, lightweight, user-friendly tool running seamlessly on a variety of platforms, maintaining its scalability for future integrations with machine learning or IoT-based systems.

- ***Programming languages:*** HTML5, CSS3 and JavaScript (ES6).
- ***Framework/Libraries:*** Bootstrap 5, Chart.js.
- ***Data format:*** JSON - JavaScript Object Notation.
- ***Version Control***: Git & GitHub.

1. Header & Navigation: Direct access to item categories and learning resources regarding water usage.

2. In the interactive calculator section, there are input fields where a user can select, or enter a quantity or frequency of use of an item.

3. Visualization Dashboard: Using Chart.js the calculated water footprint is visually displayed interactively onscreen as pie and bar graphs, which visually change interactively based on your input. This demonstrates how interactive graphics as a user interface can be more intuitive and enable nontechnical users to view complex data in an accessible format with color coded results. C. Dataset integration - We used a JSON dataset that holds predefined data of each of the everyday items of how much water was consumed, for example: 1 kg of rice → 2,500 liters; • 1 kWh of electricity → 1.3 liters Each item had the following parameters: item_name, value, unit, water_footprint_value, and an entry pointed to a URL. Any time the user selects an item from the dataset will select the value from the data set, multiply that quantity by what the value is, and will send that value to the visual layer. The modular design of the dataset allows for scaling, as well as adding additional items, simply by adding an additional JSON object, rather than modifying the core logic.

B. Visualization and Output Generation

The Chart.js library is a significant player in converting numerical data into useful visual representations.

1.A Pie Chart demonstrates contribution by category (that is, Food vs. Clothing)

2.A Bar Chart shows comparative water footprints among different items.

3..Both are interactive; hovering over a section displays precise numbers and percentages. This feature invites users to engage with different scenarios and immediately see the accumulated impact of changing a small behavior on their total water footprint.E. Testing and Optimization.

The system was tested for responsiveness, performance, and data accuracy across multiple browsers (GoogleChrome, Mozilla Firefox, and Microsoft Edge). Key findings included:

1.Average response time: < 1 second for dataset retrieval and chart readings.

2.No data loss or incorrect computations during repeated user interactions.

3.Full responsiveness across mobile, tablet, and desktop screens using Bootstrap grid layout.

Minor optimizations such as compressing JSON data and minifying JavaScript improved loading performance by approximately 15%.

III. CHALLENGES IN DOMESTIC WATER MANAGEMENT

Current IoT-enabled systems to monitor water usage have various shortcomings. Real time system responsiveness can be sluggish due to infrequent polling, over reliance on cloud computing, or a combination of the above. Some systems provide inconsistent readings due to poor sensors or incomplete calibration. Many systems also have high power consumption, making them inefficient for long term residential deployment. User experience is also a key issue. Many systems have interfaces that are cluttered, difficult to understand, or poorly designed for real-time continuous use. This system is designed for rapid and precise performance, and for ease of use, especially in the application of interface design.

IV. VOIDS IN PRESENT DIGITAL WATER SOLUTIONS.

In large part what we see is that which is put out by the global community of water management solution developers is focused on industrial and municipal scale issues as opposed to the home user. Many of these solutions are available for purchase but they do require you to pay for a subscription, work only in their proprietary cloud systems, or have complex install processes which require professional installation. Also at present the majority of these solutions do not provide per tap detail and/or a custom dashboard. Also what we see is that for data representation most of them have a set format which the user has to fit into. These gaps in the market play into the demand for modular, open source, and low cost water monitoring tools which in turn will allow users to design and tailor their own dashboards.

V. WHY CURRENT IoT WATER TOOLS FALL SHORT.

Current limitations of IoT-enabled water monitoring devices include poor real-time responsiveness that is a result of slow polling intervals and excessive dependence on the cloud. Some devices exhibit inconsistent readings due to poor quality flow sensors and uncalibrated sensors. These devices tend to have high power consumption making them inefficient for long-term residential use. User experience has been another issue of concern; user interfaces are convoluted, difficult to understand, unfit for continual monitoring, and provide poor overall user experience. These are the limitations that this system is designed to minimize by prioritizing speed, precision, and functional aesthetic design.

VI. PROPOSED SYSTEM'S DESIGN SPECIFICATION.

The sensing layer, the processing layer, and the visualization layer. We have put in place 2 YF-201 flow sensors at separate water taps which report in terms of pulse to the flow rate. The ESP8266 which is the processing layer will take in pulse frequency from the sensors and turn that into flow rate and total volume. That information is then put out to a web dashboard which reports real time of each tap's flow rate, sum totals of use, and historical data. This three layer approach we have taken is for accuracy, modularity and scale over the long term.

VII. FROM CONCEPT TO PROTOTYPE.

The development process started with calibrating the sensors so that each YF-201 unit would provide the same reading with various water pressures. The firmware is designed with an interrupt driven pulse counting to provide very certain samplings during quick reactions of flow. When developing the dashboard, we opted for features to promote optimum reading, such as color coded indicators and trend graphs. Testing for stability was concluded in several domestic scenarios and under a variety of conditions, including continuous flow, intermittent use, and fluctuations in inlet pressure - high stability was evident across all scenarios.

VIII. EVALUATION AND RESULTSOVERVIEW

The evaluation of the prototype features numerous performance and usability barometers for measurement accuracy, system responsiveness, data stability, and interpretability from the end user perspective. The evaluation evidenced that the system is a dependable and effective real tool for monitoring and understanding household water usage.

1. Accuracy of Measurements

Tests conducted in familiar domestic water-flow situations, the system displayed an accuracy of ±3% in all measurements. The accuracy is quite acceptable and satisfactory for the water monitoring devices for consumers, for all different flow rates and tolerances in the sensors. This meant the consumption values had credibility and consumers acted, resulting in a valid change in behavior.

2. System Responsiveness and Notifications

The responsiveness of the system was a potential challenge highlighted during evaluation. The system responded to the user interface within 2 seconds of the change in flow, providing feedback and evidence of changed behavior resulting in consumption change. Instant reporting in response to changes created engagement, as users could see their actions, natural turning on and off of water by turning taps on and off, resulted in consuming water. This type of short reporting interval facilitated the readership as they formed perceptions about the reliability of guessing what the system had responded to, and the responsiveness fostered the interaction with the system.

3. Stability and Continuity of Data

During the study, the data was stable, and there was no evidence of significant fluctuations, dropouts, or interruptions due to inconsistencies in others' readings. Because of the permanency of the serial data communication, and logging format and structure, all events were recorded.

4. User Interpretability, Insights

A major purpose of the prototype was to make water consumption data and usage patterns understandable for users without a technical background. Evaluation comments indicated the dashboard layout and graphics of usage trend representations provided a simple way for users to reflect on their data. Transparent indicators for daily, weekly, and monthly usage rates offered individuals a way to contextualise their footprint in a meaningful way.

Users specifically commented the value of captured daily high-usage periods, where consumption peaks—meaning the consumption was at its highest point. By simply capturing and commenting on these periods, individuals considered lousy behavioural patterns, such as over consumption during dish washing, gardening, or showering activities. Therefore, during the latter feedback process, many users determined the prototyping encouraged the user to deliberate about when and how they use water.

5. Awareness and Behaviour Change

The assessment clearly revealed more than just a change in performance; it indicated that users became more aware of their water use behaviours. Receiving alerts and recommendations in real time added an additional motivational layer to the intervention by increasing the perceived need for conscientious consumption behaviours. The combination of data quality with easy-to-use, easy-to-read data visualisations brought about a tangible change to more sustainable water use behaviours.

IX. FUTURE OUTLOOK .

The we put forth that which is very much a work in progress toward a full scale home water management system. In the coming years this project will grow to include the latest technologies which in turn will make our water use tracking better, more precise, and easier for the user. There will be large scale deployment of machine learning which will analyze trends in usage day to day and from which we will see where and when water is wasted and to that we have a solution. We will also develop dashboards based in the cloud so you can be sure the data are secure, in the cloud, and will allow a participant to access their reports anytime from anywhere. The use of smartphone apps should be a great enhancement. With the smartphone app, participant notification would be instant, they also see real time water flow values, and they control the supply of water remotely. This greatly increases convenience and access. This essentially makes the smartphone app a “smart water” monitor. The system could also have the capability of automated shutoff. Leak-detection algorithms, for example, could shut the water valve when the algorithm identifies unusual flow. This could prevent flooding or at least reduce water lost. It adds a level of safety and sustainable practice to the project that has value.

X. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS.

While these systems work particularly well in controlled environments; they exhibit limitations. The most significant limitation is the reliance on Wi-Fi, and systems cannot operate in areas where reportedly unstable signal areas are. The YF-201 sensors will require recalibrating over time depending on use in order to be accurate. The ESP8266 microcontroller has limited GPIO pins, that will limit the units that can be deployed if multiplexing methods are not utilized. Overcoming these limitations will result in new applications and advancements in reliability.

Future Directions: The system can be enhanced in multiple ways in future versions for functionality, accuracy, and scalability. The first direction, and the main way to expand, the Use Dedicated Sensors, is by utilizing machine learning algorithms in predictive analytics to identify abnormal use patterns, recommend consumption changes for each household depending on future use, and to predict use. This also allows opportunity to improve leak detection through baseline behavior for each household.

Hybrid methods of connectivity, including LoRaWAN, bluetooth mesh, and gsm modules inherently are less dependent on Wi-Fi for connectivity, and the devices can save readings temporarily in the microcontroller to sync readings at an interval later.

In future versions designed to handle variability in sensor performance, greater quality of the flow sensor may be employed, or solid-state ultrasonic sensors may also be used since these can have superior long-term stability and accuracy within tight limits. Readings can even be sustained over a wider range of household plumbing conditions by employing self calibration routines, or pressure-compensation algorithms.

This can be done with incremental development along with the move to more powerful microcontrollers based on architectures such as ESP32, or Raspberry Pi, which support far greater GPIOs, parallel processing capabilities, better connectivity options, cloud storage, and a mobile application for users to egg them on with long-term historical analytics, notifications, and cross device.

On that note, integration with smart devices, such as the smart valve system which automatically will cut flow when a leak or abnormally high consumption is detected, all will push the system from passive monitoring toward active water management with greatly reduced unnecessary consumption.

XI. EVALUATION SUMMARY .

To summarize, the prototype that was developed accomplished its original goals and, to some extent, exceeded them. The main purpose of this platform is to simplify the understanding of the processes which contribute to an individual's water-footprint. The prototype attained its original goal by creating an easy-to-use interface so that learners could quickly grasp their direct and indirect use of water resulting from any and all activities they perform and products they use daily. The tool succeeds in presenting data on "hidden" or virtual water use in a way that allows the user to visualize the concept, thereby reducing the barrier to entry for learning about their own individual water use.

The interactive aspects of the system, along with the real-time visualisation tools, greatly enhanced the engagement of learners while the prototype was being evaluated. The graphs and alerts, and other visual cues allowed learners to witness the results of their water use behaviour instantly, adjusting what is typically considered abstract sustainability metrics to more meaningful and definable metricsThis kind of interaction enhances learners' understanding of concepts as well as awareness of their own behaviour and more sustainable choices.

More importantly, this evaluation indicates that one such digital technology can be influenced and is impactful in supporting awareness of water use and environmental education and responsibility. The application exploits the benefits of environmental education, a clear and actionable interface, and easy, non-intrusive behaviour change.

We also learned that this prototype has the ability to reach a very broad and diverse audience with sustainability information. Unlike static education resources, which are a fixed source of information, this dynamic platform has continually adaptive and multi-faceted learning approaches. The modular architecture will eventually allow the system to be expanded, employing more sensors, categories of use or analytics constructs. In summary, this evaluation outlines the potential impact of the prototype as a significant tool for environmental education worldwide. Making consumption footprint data, understanding data and taking action all very accessible, we witness a more aware consumer and product responsibility in the environment.

XII. CONCLUSION.

This study illustrates how inexpensive IoT devices may change domestic water management because it is supplying real-time, actionable information. As such, this system provides highly accurate data at the tap level for consumers, thus permitting the consumer to make informed decisions to decrease wastage. Such solutions may become a pragmatic step toward sustainable lifestyles as challenges in water availability aggravate. With the rapid depletion of fresh water resources, and the expectation of these resource levels to be further strained by rising demands due to domestic consumption, there is an urgency for new data-driven solutions that are inexpensive and will be useful in raising awareness about people's water usage patterns. Thus, this study aimed at addressing the critical gap of household water awareness through the design and realization of an IoT-based real-time water footprint monitoring system, with dual YF-201 flow sensors interfaced with an ESP8266 and a real-time dynamic web dashboard. We showed in this study that effective water footprint management does not require complex industrial architecture with high-end metering devices – but can be effectively realized through the integration of inexpensive hardware, effective firmware, and effective data visualization.

Results from the prototype testing indicate that users gain greater awareness and make more informed choices when provided with tap-wise consumption metrics. Original data allows users to pinpoint patterns that traditional meters cannot detect, such as times of consumption while engaged in routine tasks, leaks, and whether flow is wasted. For households with high water use, the act of differentiating taps quickly points to inefficiency and clarifies patterns of inefficiency and waste with unprecedented resolution. The data provides evidence that an increase in visibility begets accountability, and an increase in accountability begets conservation.

Additionally, the system architecture has proven reliable, responsive, and adaptable. For instance, the ESP8266 was built with native Wi-Fi capabilities that was able to enable smooth data transfer with minimal latency, all while powering the dashboard interface which reported flow rate, accumulation, and trends over time. Overall, this puts the system in a great position for further development for advanced smart water applications at larger scales. Furthermore, it has also been designed from the stand-point of modularity, so scaling it at a later stage to more taps, integration to a cloud platform, or development of automatic shut-off features will be an easy process, which further increases its value proposition as a scalable home utility device. In addition to these positive findings the study reiterated a number of areas for further improvements. The number of calibration complications that arose from variable water pressure, sensor aging and variances in local plumbing has evoked that the system can be improved upon, and that better compensation algorithms could be developed. Likewise, dependence on local Wi-Fi networks suggests local offline first architectures or hybrid communications architectures should also be seriously examined when trying to improve reliability of the system in low signal or rural context. Reflection upon these performance limitations must be considered when deploying at scale whether that be in household or community contexts.

These performance limitations must be critically considered when scaling deployment, especially in various household or community contexts.Broader, this project is attempting to democratize environmental data through IoT. As water stresses become increasingly acute globally, empowering laypersons to observe signals in real time is not only very useful but also very important work. Domestic users constitute the last link in the resource consumption chain, and offering timely and accurate water intelligence has the potential to facilitate significant reductions for water wasting, at scale. Findings from this work support the reinforcing hypothesis that laypeople are so much more likely to adopt sustainable behaviour, detect leaks sooner, and assume agency as stewards of critical resources, when they are able to see their consumption.

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