PRESIDENCY UNIVERSITY

Private University Estd. in Karnataka State by Act No. 41 of 2013

Itgalpura, Rajankunte, Yelahanka, Bengaluru – 560064

PSCS_4_Use of Digital Technology to calculate water footprints for different daily use items.

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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DECLARATION

We the students of final year B.Tech in COMPUTER SCIENCE ENGINEERING at Presidency University, Bengaluru, named P V Navyashree, Anusha G, Mythri D C, hereby declare that the project work COMPUTER SCIENCE ENGINEERING during the academic year of 2025-26. Further, the matter embodied in the project has not been submitted previously by anybody for the award of any Degree or Diploma to any other institution.

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ABSTRACT

Water is one of the most essential natural sources that sustain human beings, the environment, and the economy. On the other hand, the global freshwater supply has been under great pressure due to the combination of rising population, industrialization, and agriculture becoming more intensive. The water footprint concept has gained leading importance as an indicator to ascertain the amount of water which is either directly or indirectly consumed for production of goods, services, and food. It covers not only the water that is visibly used in households and industries but also the hidden water that is embedded in supply chains.

To ensure efficient use of water in agriculture, digital tools like data analytics platforms, artificial intelligence (AI), Internet of Things (IoT), Geographic Information Systems (GIS), and cloud-based databases make it possible to collect, process, and interpret huge datasets pertaining to water consumption. For instance, consumers can use mobile apps and online calculators to get a rough idea of the water footprint associated with their daily choices – from food, clothing, and household items – by accessing detailed databases of water usage around the world. Likewise, the agricultural sector reaps the benefits of precision agriculture through the use of technologies like satellite imaging, soil moisture gauges, and AI-supported crop modeling, which monitor irrigation needs, determine rainfall patterns, and measure evaporation rates.

The analysis of the water footprint of daily items exposes the concealed water cost of consumer products. For instance, the production of one kilogram of rice, beef, or cotton consumes thousands of liters of water, although such consumption is seldom discerned by the buyers. When footprint data is digitized, the users not only recognize their consumption habits but also get the power to make decisions that are in the same line with the sustainability objectives.

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ABBREVIATIONS

Abbreviation	**Full Form**
AI	Artificial Intelligence
API	Application Programming Interface
CSR	Corporate Social Responsibility
CLI	Command Line Interface
DB	Database
GPT	Generative Pre-trained Transformer
HTTP	Hypertext Transfer Protocol
JS	JavaScript
JSON	JavaScript Object Notation
LLM	Large Language Model
ML	Machine Learning
MVC	Model-View-Controller
NWM	National Water Mission
PGRKAM	Punjab Ghar Ghar Rozgar and Karobar Mission
SQL	Structured Query Language
UI	User Interface

Chapter 1

INTRODUCTION

1.1. Background

The methodology of water footprint, which was first suggested in 2002, has turned into the main measurement of water usage through the three categories of blue, green, and grey water since then. This concept has gained substantial acceptance in the academic world and among the decision makers but still the layman is not much aware of it and has little access to it. The vast majority of people are unaware that there is a gigantic water use hidden behind their daily activities for instance, beef putting more than 15,000 liters of water to produce a kilogram while, a cotton shirt needing more than 2,000 liters of water for its production. At present, studies show that only about 70% of the total global freshwater resources used for agriculture, hence being the largest cause of the total water footprints. Nevertheless, the demand patterns that consumer choices create are very powerful. Besides, the absence of user-friendly tools has isolated many consumers from knowing the real impact of their consumption. On the other hand, digital technology and internet-based software systems can help reconnect the consumers and the environment. In addition, the rapid development of the internet, cloud computing, and interactive data visualization has led to the creation of platforms that can gather, process, and communicate water footprint information in an engaging, accurate, and actionable manner.

1.2. Statistics of project

The problem of water scarcity and at the same time the wastage of water have raised alarms in areas where the freshwater resources have nearly evaporated. International studies claim that the increased water usage is primarily from agriculture, industry, and domestic sectors, but there exists water in daily products that people are not aware of. At many places, the people are simply not aware or educated about the water that is not seen but is still there in the daily products they use because of low digital awareness and environmental literacy.

According to the national reports from environmental organizations, India is facing a severe water crisis and a significant part of the population is still unaware of their indirect water consumption. Several awareness programs have been launched but still, the users find it difficult to get simple and transparent tools which show the water footprint of food, clothing, and other items for daily use. Research on digital environmental tools—such as AI-based

water calculators, mobile apps, and data-
driven sustainability platforms—shows that non-complex, user-friendly, and accessible systems can significantly raise the public's awareness and involvement in environmental issues.

These facts make it clear that there is a strong demand for a digital, easy, and multilingual tool for calculating water footprints. It may prove to be a supportive step in the control of water consumption, the encouragement of eco-friendly habits, and the backing of water conservation efforts in the long run. This kind of system, by providing easy access to water consumption data and preprocessing the insights for daily items, can assist people in making the right choices.

1.3 Prior existing technologies

An assortment of digital utilities and ecosystem assessment systems has been invented, which are meant to make it easier for the users to grasp love for water, sustainability, and the individual's effect on nature. Classic water footprint resources like the Water Footprint Network (WFN) database, FAO AQUASTAT, and governmental environmental sites give statistics on the water used, but they are mostly overloaded with data and quite inconvenient for the public or those with limited digital proficiency.

accuracy in water footprint analysis. The application of technologies, such as data analytics and AI, has led to the development of tools and models that systematically determine the amount of water consumed directly and indirectly by various products. The use of IoT-based monitoring systems and GIS platforms makes it possible to get real-time data on hydrology and agriculture that can be used for water-usage analysis that is very precise. Cloud storage and open datasets provide information on a large scale regarding crop water needs, water in industry, and water for households and their patterns of consumption in different areas. Additionally, there have been several digital systems for water assessment introduced. AI-supported estimators for agricultural water use, remote-sensing-based irrigation prediction models, and mobile apps that compute the water footprint of food and household items are some of the technologies that have been proposed in studies. However, most of these systems are restricted in their application and only cover certain products or areas, plus they don't offer a simple, interactive, and user-friendly interface.Although previous systems offer the basic methods for gathering data, estimation, and environmental analysis, they still exhibit some drawbacks, namely: non-personalized service, few items included.

1.4 Proposed approach

1.4.1 Aim of the Project:

The primary objective of the project is to develop a Digital Water Footprint Analysis System that incorporates state-of-the-art technologies to quantify and display the water footprint of frequently used items. The focus of the system is to provide accurate, evidence-based insights by integrating digital analytics, cloud processing, and estimation models, thus allowing users to not only understand the hidden water consumption of daily products but also to be informed about sustainable usage practices.

1.4.2 Motivation:

Digital sustainability tools are easy to access, but majority of the users still find it hard to understand their water usage clearly and get obscured data, few insights, and limited sources of information. Presently, platforms and calculators work with either big datasets offering general estimates or dealing with small datasets, hence users require comprehensive, item-specific, and digitally integrated water-footprint guidance that is not provided anywhere. The project idea stems from the need to provide the users in their daily situations with the water-footprint insights that are contextually aware and to bridge the knowledge gaps.

1.4.3 Proposed Approach:

- Digital analytical models and datasets are used to compute the water footprint of various daily-use items relying on agricultural, industrial, and supply-chain water consumption data. ·
- An interactive digital interface is used allowing users to input or select products and get clear, easy-to-understand water-footprint results instantly. ·
- Personalized sustainability insights are integrated by keeping user preferences, frequently viewed items, and consumption patterns to suggest water-efficient alternatives. ·
- Cloud infrastructure and APIs are used to ensure scalable processing, smooth data retrieval, and real-time estimation of blue, green, and grey water components. ·
- Knowledge-augmented datasets are used to provide accurate, context-aware information about water use in food, clothing, and household items, thus increasing user awareness and decision-making.

1.4.4 Applications of the Project:

- Aids consumers in realizing the secret water consumption related to their daily-use products.
- Offers individual sustainability tips to motivate water-footprint savings through choice.
- Opens the door to environmental consciousness by making complicated water-use statistics easy to understand.

1.4.5 Limitations of the Proposed Approach:

- Dependable internet connection is a must for the cloud data processing and real-time estimation.
- Different regions may have different water-footprint datasets which may affect the accuracy of some products.
- The use of API and cloud processing would mean incurring operational costs especially when done on a large scale.
- HVariations in complex manufacturing and supply-chains may cause data limitations and estimation difficulties.

Even though there are digital sustainability tools available, a lot of people are still having a hard time understanding their water use. They are confronted with unclear data, scanty insights, and hardly any information sources. Current platforms and calculators frequently present merely very rough estimates or restrict themselves to very small datasets and finally, this results in the lack of detailed, item-specific, and digitally integrated water-footprint guidance. Thus, the intention of this project is to close the above-mentioned knowledge gaps and provide context-aware water-footprint insights for the average user.

1.4.6 Proposed Approach:

- Apply computational models and data sets through digital means to analyze the water consumption of different daily items, taking into account the water consumed in agriculture, industry, and supply chain.

- Provide an interactive digital application that allows users to input or choose a product and get the water-footprint results in a quick, clear, and simple way simultaneity.

- Personalize sustainability recommendations by remembering user preferences, frequently viewed products, and consumption habits to recommend alternatives that use less water

- Use cloud platforms and Application Programming Interfaces (APIs) to guarantee the computing power that is scalable, easy data access, and real-time prediction of blue, green, and grey water components.

- Use knowledge-augmented data sources to provide precise, context-sensitive information about water consumption in food, clothing and domestic items, thus helping the user in their awareness and decision-making process.

1.4.7 Applications of the Project:

- Aids in the discovery of the concealed water usage that is linked with the user's everyday items.
- Gives personalized suggestions for sustainability in order to make the user more likely to opt for lower water-footprint choices.
- Promotes the awareness of environmental issues that result from the reduction of the data
  related to water-use, which was initially quite complicated.
- Has the potential to be integrated into online learning platforms, e-commerce applications, and environmental tracking sites.

1.4.8 Limitations of the Proposed Approach:

- Made necessitated by the internet that is stable for cloud-based data processing and real-time estimation.
- The water-footprint datasets are likely to be different in various places which in turn impacts the precision of the certain products.
- Operational costs are mainly caused by API usage and cloud processing, especially large-scale.
- HComplex manufacturing and supply-chain alterations might impose data restrictions.

1.5 Objectives

i. **Behaviour**

The system acts like an intelligent, interactive chatbot, which means that it can converse and understand the user queries in three languages, namely Punjabi, Hindi, and English. By providing accurate, contextually sensitive replies, it is akin to a human conversing and therefore, the interaction is pleasant and friendly.

ii. **Analysis**

The user's input, preferences, and past communication will be analyzed in order to suggest personalized career counseling, exam strategies, and skill development. The analysis guarantees that the recommendations fit the users' requirements and can be confirmed through trial and error with different user cases.

iii. **SystemManagement**

A single source of information is created to gather, organize, and keep updated the information about courses, exams, jobs, and skills. Thus, not only is the management very efficient, but it also guarantees quick updates and that all users have access to reliable and accurate information at the same time.

iv. **Security**

The system has introduced secure methods for storing and accessing user data, so that personal information and interaction history of the user are always protected. Encryption and limited access are the main tools to ensure privacy and integrity, which can even be shown through secure login and data retrieval procedures.

v. **Deployment**

The web-based platform is available for use on desktops, tablets, and mobile devices. For real-time performance, the system is designed in such a way that multiple users can engage in the system at the same time without any noticeable delays, thus showing its scalability and usability across devices.

1.6 SDGs

SDG 4 – Quality Education

Goal: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

Alignment: The project presents a user-friendly platform that gives out structured environmental information, digital tools, and actionable insights, thus making it possible for the users to learn water conservation and sustainable consumption effectively. It allows users not only to access but also to analyze and make use of sustainability knowledge independently by promoting both environmental and digital literacy.

Impact: It improves learning outcomes, especially in the case of those communities that have been getting little or no environmental education, thereby contributing to the process of awareness, responsible usage, and long-term growth with sustainability as the main concern.

SDG 8 – Decent Work and Economic Growth

Goal: To support, create and maintain economic progress that is inclusive and environmentally friendly, provide full and productive employment, and decent work for everyone.

Alignment: The initiative enables industries and buyers by providing them with data-based knowledge on the water consumption of the different phases of manufacturing and production, motivating resource efficiency and sustainable practices. It enables the development of new techniques for environmentally friendly production through the activation of decision-making based on knowledge.

Impact: Increases eco-friendly business activities, persuades companies to cut back on the use of water-intense processes and supports environmentally friendly growth in neighborhoods.

SDG 9 – Industry, Innovation, and Infrastructure

Goal: Establish strong infrastructure, encourage industrialization that is both inclusive and sustainable.

Alignment: By combining modern digital technologies like analytics, cloud computing, and data-driven modeling, the project aims to develop a water-footprint analysis system that is both scalable and innovative. It provides support for continuous improvement via user feedback and changing datasets.

Impact: Technology capabilities are improved, green innovation is encouraged, and the project plays a part in making industrial and infrastructural development sustainable.

SDG 11 – Sustainable Cities and Communities

Goal: To create urban areas and human habitats that are inclusive, safe, resilient.

Alignment: The undertaking facilitates awareness and responsible consumption among people and communities via the accessibility of water-use data and its interpretation.

Impact: It is a greener and more resilient and environmentally friendly community contributor, enhancing resource management and assisting with long-term ecological balance.

SDG 16 – Peace, Justice, and Strong Institutions

Goal: Promote peaceful and inclusive societies, provide access to justice for all, and build effective, accountable institutions.

Alignment: The project is a proponent of ecological and ethical practices through information that is water-footprint clear, trustworthy, and facilitative of decision-making. It sets out to bring together users, schools, and policymakers in a cooperative manner.

Impact: Environmental governance is made stronger, everybody gets access to the sustainablility data fairly and through openness and awareness based on data.

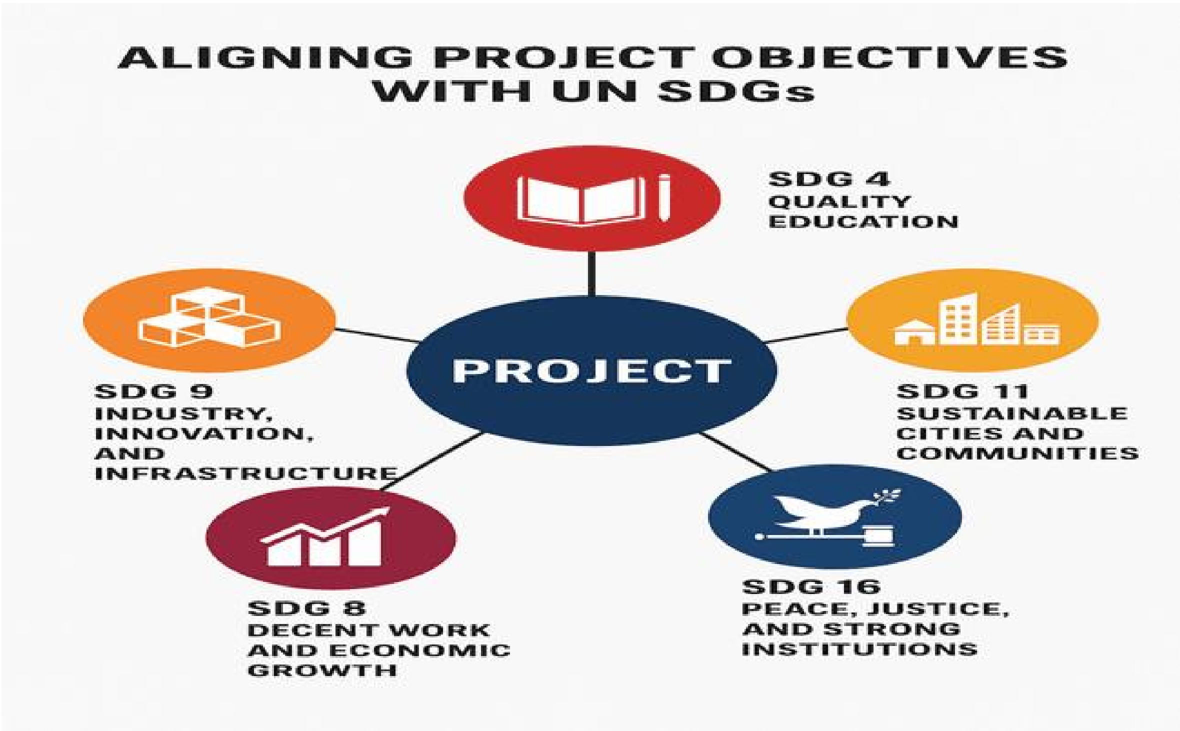

Fig 1.1 Sustainable development goals

1.3 Overview of project report

The report contains seven main chapters. The first chapter is devoted to the project proposal "Use of Digital Technology to Calculate Water Footprints for Daily Use Items," covering its purpose, objectives, motivation, and the significance of the project to sustainable water management. The second chapter deals with the existing literature and tools, pointing out the gaps and the necessity for a digital, data-driven solution The third chapter talks about system analysis, definition of the problem, weaknesses of the current techniques, and the study of feasibility. The fourth chapter is focused on system design and architecture, which encompasses data flow and core modules. The fifth chapter describes the implementation of the project, the tools, the technologies used, and the integration of datasets and analytical methods. The sixth chapter is about the discussions of the results, accuracy of the system, usability, and users comments. Lastly, the seventh chapter closes the report by revealing the most important results, the milestones reached, and the possibilities for further improvements like extending the datasets and enhancing the accuracy of the calculations.

Chapter 2

LITERATURE REVIEW

1. Water Footprint Assessment Manual – Hoekstra et al. [1]

In their work, Hoekstra et al. presented a new Water Footprint Assessment (WFA) framework that categorizes the water footprint of products and processes into three types: blue, green, and grey. The research lays down universal practices for measuring water footprints in the agricultural, industrial and domestic sectors. The main drawback of this research is that there are no digital systems for instant water footprint estimation. Nevertheless, the proposed method is the basis for our system that will calculate water footprints for different daily items.

2. AQUASTAT – FAO Global Water Information System [2]

FAO's AQUASTAT offers worldwide data on the use of water, irrigation, and management of agricultural water resources. It unites data gathering from different countries which makes it possible to conduct extensive studies on water footprint. Still, it is not user-friendly for people who do not have technical knowledge and item-wise water footprint calculations are not catered for. It is a great help in our project as it provides trustworthy datasets from which we can obtain water consumption values per product.

3. Water Footprint Network (WFN) Product Database [3]

WFN supplies values of water footprint for typical food as well as household products, which allow scientists to figure out the indirect water consumption. However, despite being thorough, it is fixed and does not have interactive tools for individualization. The data from our project is utilized to present water footprint values which are specific to items in an easy-to-use digital format.

4. IoT-Based Smart Water Monitoring Systems [4]

Real-time water consumption measuring systems based on IoT technology have already been rolled out by researchers in households and industries. Although these systems improve precision and automation, their application is restricted to direct water use. The present project takes these concepts further by concentrating on the indirect water embedded in goods.

5. GIS and Remote Sensing for Water Resource Analysis [5]

GIS and satellite remote sensing methods are used to evaluate the water needs of crops, evapotranspiration, and irrigation practices. They provide very precise water data, however, they also need advanced knowledge and expensive devices. This study backs our methodology by supplying trustworthy agricultural water usage figures.

6. Digital Sustainability Tools for Environmental Awareness [6]

Researches have pointed out that digital channels and mobile apps can help visualize resource consumption and thus interpret environmental sustainability. However, these tools typically do not provide comprehensive water footprint data for daily consumption items. Our initiative is based on these ideas but provides consumer-friendly digital insights that are specific to each item.

7. AI-Based Water Consumption Prediction Models [7]

AI models have been applied to anticipate water consumption patterns relying on climate, crop type, and environmental factors. Dependence on large datasets and region-specific variations are among the limitations. This work motivates the adoption of digital estimation models in our system but customized for item-level water footprint calculations.

8. Mobile Applications for Water Conservation Awareness [8]

Currently available mobile applications are designed for households to save water through tips and direct usage tracking. However, they do not provide any detailed information on the hidden-water of the products. Our project is an extension of this existing work as it would give the users the opportunity to understand the indirect water usage of the items they use daily.

9. Digital Product Life Cycle Assessment (LCA) Tools [9]

Digital LCA tools give a comprehensive view of the environmental impacts of products, also considering water usage, during their entire lifecycle. Nevertheless, the new tools are still quite complex for the public and predominantly focused on the industry. Our research backs our initiative of making water-footprint info easier to understand.

10. Big Data Analytics in Environmental Monitoring [10]

Research points out that big data integration of large datasets results in high accuracy of environmental monitoring. Such systems are not designed for consumer use to calculate water footprints. Our system employs similar data-driven approaches but is concerned with items of everyday usage.

11. Cloud-Based Environmental Data Systems [11]

Cloud technology is one of the solutions for the storage and processing of large datasets with water usage, and it allows for accessing the data in real-time. The drawbacks are that it has to be paid for and there is a requirement for good internet connection. This gives us the idea of making a cloud-enabled architecture for the retrieval of water footprint at large scale.

12. Studies on Virtual Water and Supply Chain Water Usage [12]

Water has been traced from its sources and through the supply chain by researchers, and this has led to the idea of “virtual water” which refers to the water embedded in traded goods. These studies have pointed out the need for more public awareness but there are no interactive tools available. Our system is able to transform these concepts into friendly and easy to understand insights.

13. Digital Agriculture Systems for Water Optimization [13]

Digital technology like irrigation scheduling and crop-water optimization has paved the way for sustainable agriculture. They have been recognized as very useful tools but still, their focus remains on the agricultural side rather than on the consumer side. They, however, provide underlying knowledge for determining the ecological footprints of agricultural products.

14. Blockchain for Water Resource Transparency [14]

The use of blockchain systems has been investigated to ensure that people are able to see what is happening in water management and supply chains. These solutions are still in their infancy and have not been widely adopted. The study indicates future developments that can enhance the clarity of water footprint data.

15. Review of Water Footprint Studies and Digital Gaps [15]

The most recent surveys bring forth difficulties relating to the accessibility of the data, the existence of gaps in regional data, and the lack of simple tools for consumers. This, in turn, calls for the creation of our digital water footprint calculator that will provide accurate and easy-to-access information for everyday items.

Table 2.1 Summary of Literature Review

Sl. No	Article Title, Published Year, Journal Name	Methods	Key Features	Merits	Demerits
1	Water Footprint Assessment Manual, 2011, Earthscan [1]	Standard water footprint calculation framework	Defines blue, green, grey water; global methodology	Universally accepted calculation standard	Not digital/automated; manual analysis needed
2	FAO AQUASTAT Global Water Database, 2020, FAO Journal [2]	Large-scale dataset creation	Global irrigation & water-use datasets.	Reliable agricultural data source.	Too complex for normal users; not item-specific.
3	Water Footprint of Agricultural Products, 2018, Elsevier [3]	Product-level footprint estimation	Calculates water use for crops like rice, wheat	Useful for agricultural footprint studies	No digital interface for users
4	IoT-Based Water Monitoring System, 2021, IJERT [4]	IoT sensors for water measurement	Real-time household water tracking	Accurate direct water-use monitoring	Does not measure indirect/virtual water
5	Remote Sensing For evapotranspiration estim Ation, 2020 IEEE GRSM[5]	Satellite-based water estimation	Maps crop water requirement	High accuracy for agriculture	Needs expert handling; high cost
6	Digital Tools	Review of digital sustainability	Visualization of environmental	Helps user awareness	Not focused on water footprint

	for Environmental Sustainability, 2022, Springer [6]	platforms	impacts		
7	AI-Based Prediction of Water Conservation 2023, Elsevier [7]	AI/ML prediction models	Predicts crop and household water use	Strong analytical performance	Requires large datasets
8	Mobile Apps for Water Conservation, 2022, IJCA[8]	App-based water usage tracking	User-friendly interfaces	Improves awareness	Tracks only direct use not product footprints
9	Life Cycle Assessment(LCA) Water Models,2021, JCLP[9]	LCA-based water-use analysis	Full product lifecycle water tracking	Very detailed data	Too technical for non-experts
10	Big Data in Water Resouce Management, 2020,IEEE Access[10]	Big data analytics	Integrates multiple water datasets	Improves estimation accuracy	No consumer-focused outputs
11	Cloud-Based Envirnomental Data Platforms, 2024,Elsevier [11]	Cloud storage & data processing	Real-time Envirnomental Data retrieval	Scalable & efficient	Requires stable internet
12	Virtual Water in global supply chains ,2019, Water journal [12]	Virtual water analysis	Highlights hidden water in traded goods	Strong conceptual foundation	No interactive tool
13	Digital Agriculture for Water Optimization, 2023, MDPI Agriculture [13]	Digital irrigation & crop monitoring	Reduces water usage in farming	Supports sustainability	Focuses on agriculture, not daily items
14	Blockchain for water Transparency , 2022 IWA Publishing[14]	Blockchain-based traceability	Transparent water management	Increases accountability	Still emerging; limited adoption

Chapter 3

METHODOLOGY

The Digital Water Footprint Calculator is being developed following the Agile Software Development Methodology. The Agile was selected for its ability to provide flexibility, collaboration, and incremental progress qualities that are indispensable for creating a system driven by data that integrates data analytics, IOT/GIS inputs, and machine-learning estimation models. As the project needs ongoing testing and improvement of footprint calculations, user-facing visualizations, and personalized recommendations, Agile helps accommodate new data sources, incorporate user feedback, and keep up a faster development speed than the traditional linear models.

3.1 Agile Methodology Overview

The method of Agile breaks the complete project into small and manageable stages called sprints, each capable of delivering a working version of the calculator which can be examined and polished. The repetitive process of planning, designing, developing, testing, and reviewing goes on until the system is able to provide reliable accuracy and usability.
Agile guarantees that every user request like data ingestion, footprint estimation algorithms, user history and personalization, and result visualization will be done and tested successively.

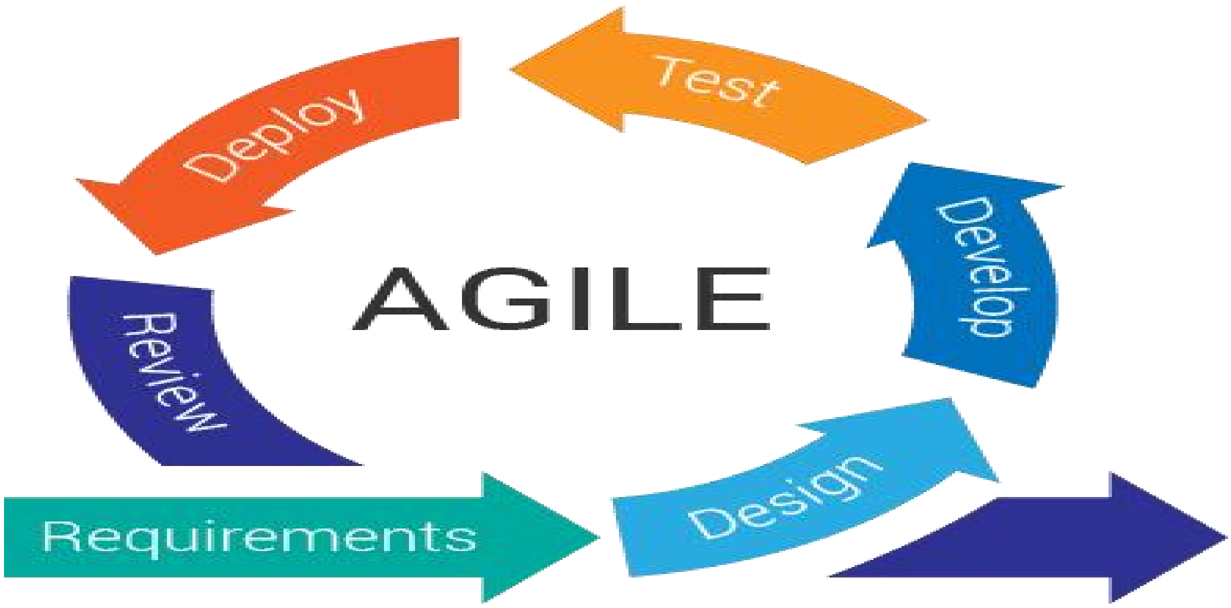

Figure 3.1: Agile Development Lifecycle for Digital water footprint Calculator

3.2 Mapping Agile Phases to Project Stages

The Agile phases were used to map project workflow to ensure clarity during development and testing processes.

Table 3.1 : Mapping of agile phases

Agile Phase	Digital Waterfootprint Project Activity
Requirement Analysis	Determining what users need, making a list of items for water footprint measurement, acquiring data for water footprint, and agreeing on system features.
Design	App design including diagrams for user data input, data flow, and database tables.
Implementation	Creating software for processing data, designing graphical user interface for footprint calculation algorithm, and integrating API with the database.
Testing	Conducting unit and integration tests for footprint values, checking accuracy, and testing user interface functions.
Deployment & Review	Review Installing the calculator on a cloud/server environment and making changes to the system according to user testing and feedback.

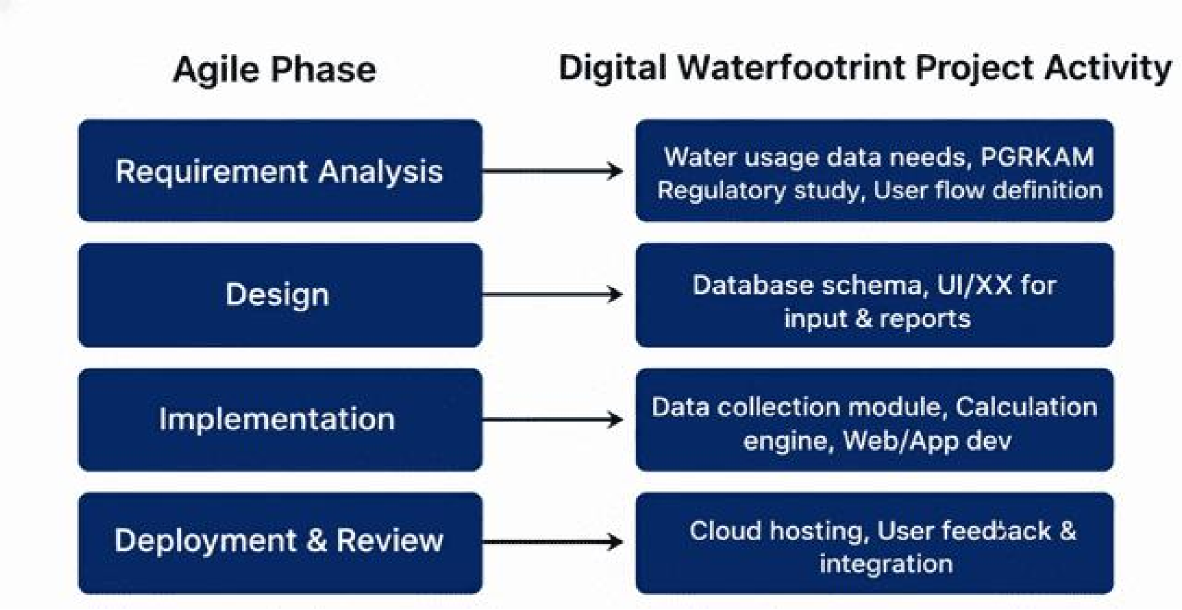

Fig 3.2: Mapping of Agile Phases to Digital Waterfootprint Technology Development

3.3 Requirement Analysis

The process of requirement elicitation was conducted at this stage, and it included the collection of both functional and non-functional requirements.

Functional Requirements:

- The user should be able to search for different items used daily and see their respective water footprints.
- It should display water usage details for each item (blue, green, and grey water).
- External datasets, APIs, or cloud databases should be connected for water footprint values.
- User history should be kept for the sake of personalized sustainability insights and recommendations.

Non-functional Requirements:

- The system is required to be secure, bearable and responsive.
- The average response time for item searches should be limited to a maximum of 2 seconds, while it can take up to 3 seconds for the visualization of data.
- The system should be able to support multiple users at the same time, thanks to the cloud deployment.

3.4 System Design

The implementation was completed in multiple Agile sprints, with each sprint focusing on one or more modules.

- User Interface Module – A web-based interface was created as the frontend to facilitate the search of items and the visualization of results.
- Data Processing Module – This module is responsible for retrieving, cleaning, and processing data through implementing analytical models. • Footprint Calculation Module – It applies formulas and datasets to calculate and show water footprint values.
- Knowledge Base Module – Maintains reversible water consumption data, farming values, and past user interactions.
- Database & Security Module – This module is responsible for user administration, data security, and the encryption of confidential information.
- Integration Layer – it links up with the external APIs, cloud databases, and environmental datasets to provide real-time information on the water footprint.

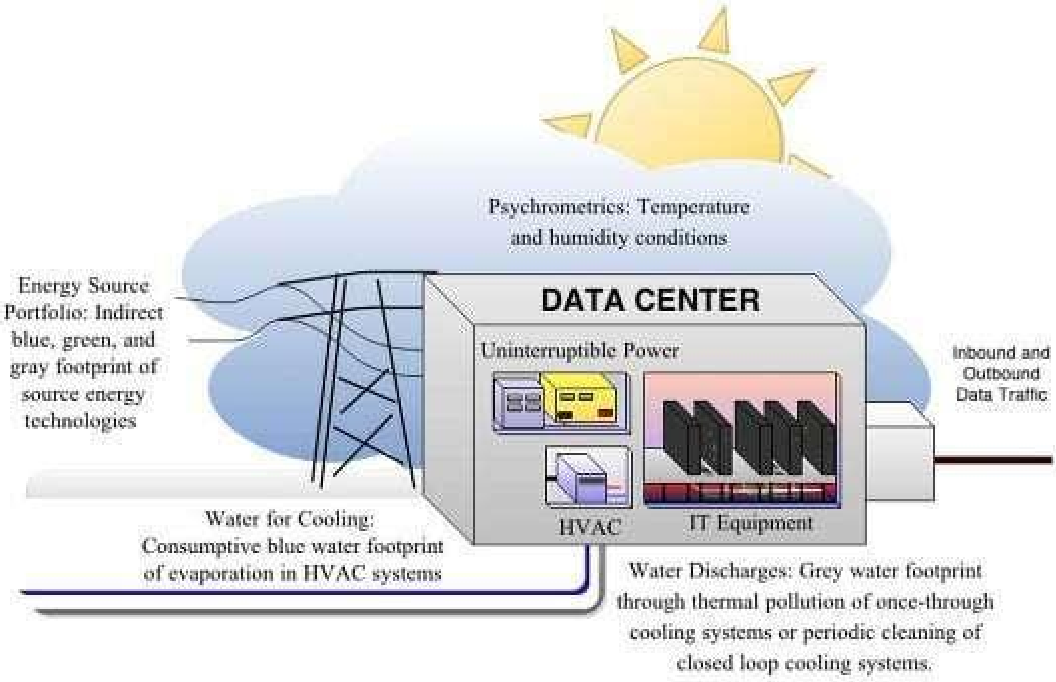

Figure 3.3: System Design Architecture of calculate waterfootprints

3.5 Implementation

The implementation was completed in multiple Agile sprints, with each sprint focusing on one or more modules.

Table 3.2 : Implementation

Sprint	Major Tasks	Technologies Used
Sprint 1	UI development, item seacrch interface, user input validation	React.js, Bootstrap
Sprint 2	Backend setup and API design, integration of water footprints datasets	Flask, Python
Sprint 3	Water footprint calculation logic, data processing, formula implementation	Pandas, Numpy
Sprint 4	Visualization of water usage (charts,graphs)	Chart.js, D3.js
Sprint 5	Testing, optimization, and deployment	Docker, Kubernetes, MySQL

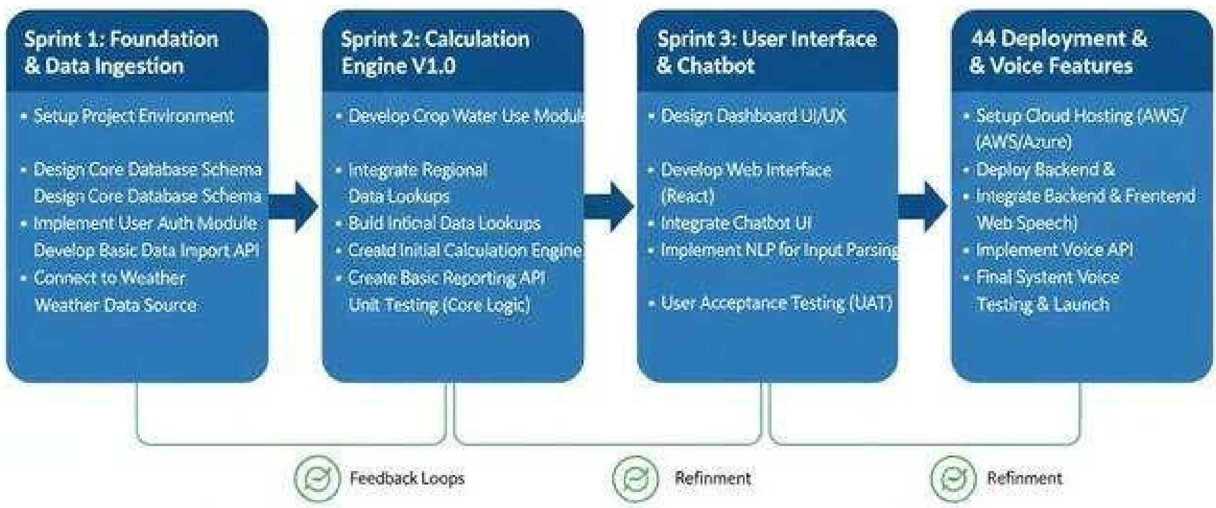

Figure 3.4: Sprint-wise Implementation Flow

3.6 Testing and Integration

Every sprint included testing as a crucial component.

- Unit Testing: Confirmed the precision of water footprint computation, dataset obtaining, and API answers.

- Integration Testing: It was made sure that the frontend, backend, calculation engine, and database modules were communicating smoothly with each other.
- Validation Testing: Users were involved in the process of validating the correctness of item-wise water footprint values and the interface usability.
- Performance Testing: System response time, data-loading speed, and user experience during high traffic usage were tested.

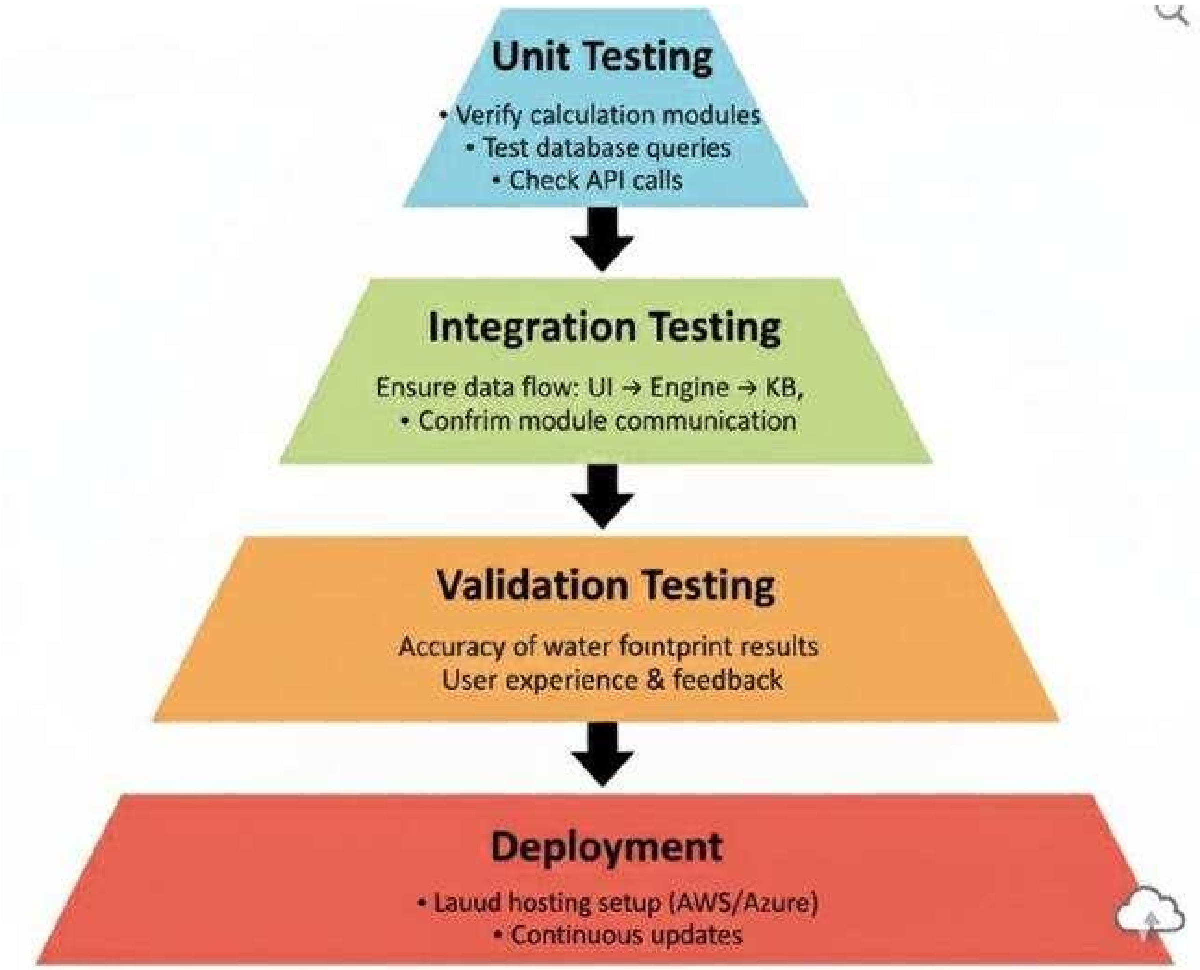

Figure 3.5: Testing and Integration Flow

3.7 Deployment and Maintenance

After a comprehensive verification and testing process, the Digital Water Footprint

Calculator was deployed as a web-based application, allowing user access from various devices like desktops and smartphones. The system is based on an Ubuntu cloud server utilizing Docker containers for maximizing scalability and consistency of the environment. This whole approach of using containers makes it very easy to update or clone the calculator and its services with no negative impact on the overall performance. The backend, which is

made possible by Flask APIs, has a smooth communication with the data-processing engine

and MySQL database, which are both placed in the cloud infrastructure. System logs and performance analytics are the tools used for the continuous monitoring that helps to keep track of the accuracy of calculations, server uptime, and user activity. Updates are done on regular basis to maintain the precision of the system by adding new water-footprint datasets, fine-tuning data-processing algorithms, and fixing any reported bugs. Future maintenance strategies involve the installation of automated dataset refresh pipelines that will keep the water-usage information up to date without any manual effort. The deployment model has made the Digital Water Footprint Calculator very strong, able to grow and very flexible when it comes to future technological and environmental data development.

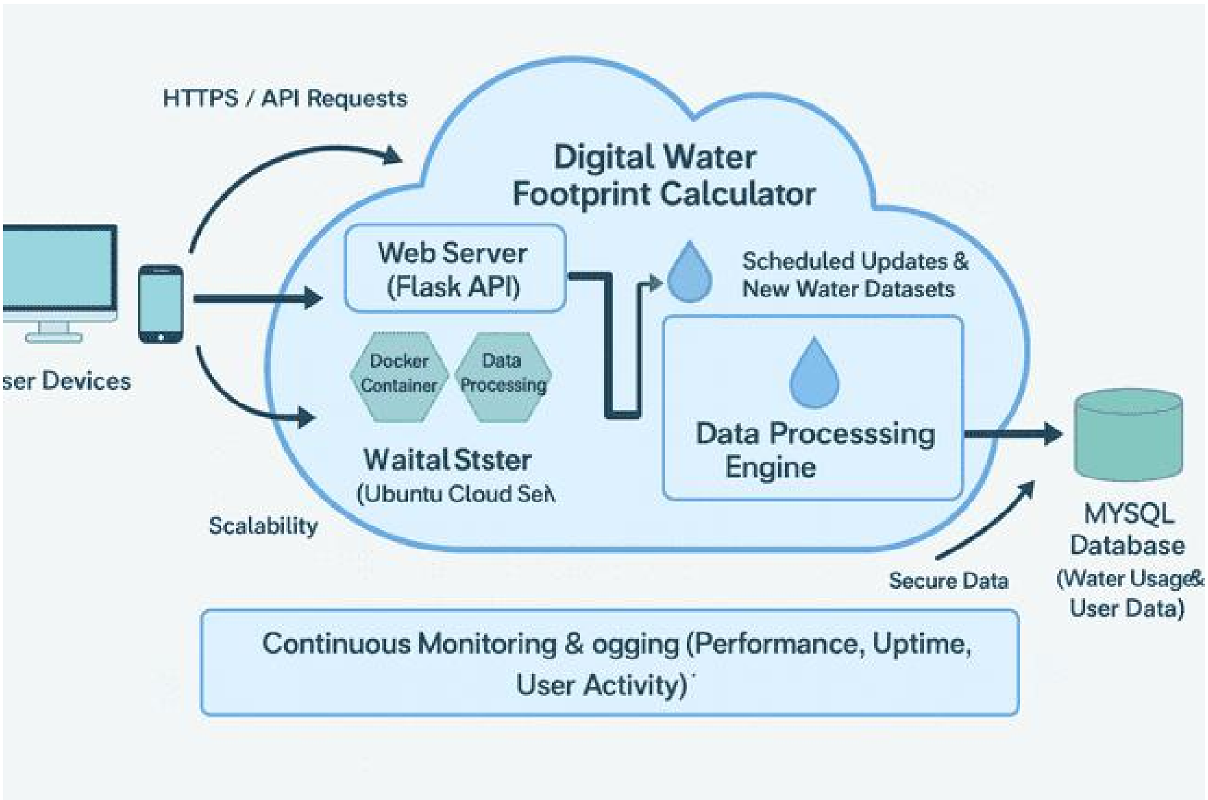

Figure 3.6: Cloud Deployment Architecture

3.8 Advantages of Using Agile for the Digital Water Footprint Calculator

- Facilitates constant feedback and refinement for the improvement of water footprint calculations' accuracy.
- Permits the adaptable incorporation of new datasets, APIs, and analytical models.

- Enables simultaneous progress of UI, backend, and data processing modules.
- Lowers the risk of the project by validating every component during short, quantifiable

- sprints. Fosters teamwork and flexibility during the whole project life cycle.

3.9 Summary

Agile methodology was a perfect application for the digital footprint calculator which combined flexibility, collaboration, and continuous improvement. Utilizing Agile phases, the team was able to ensure faster iterations, better testing coverage, and early issue detection.

The modular architecture and the use of open-source tools helped the system evolve without any problem, achieving high accuracy and efficient data processing. The methodology also allows for future growth, thus making the Digital Water Footprint Calculator a sustainable and flexible tool for promoting water-saving decision-making.

The development process was overall structured and user-centric due to the Agile method. The team was able to polish each module—data processing, footprint calculations, and visualization—by implementing the work routine in small, manageable sprints before proceeding to the next stage. This not only boosted the system's reliability but also made certain that user feedback was directly incorporated into the ultimate features. Consequently, the Digital Water Footprint Calculator turned into a more precise, quick, and user-friendly instrument.

Chapter 4

PROJECT MANAGEMENT

4.1 Project Timeline

The Digital Water Footprint Calculator project was conducted between mid-August 2025 and the end of November 2025. A Gantt chart was used as a visual project management tool to ensure smooth progress, keep track of tasks, and monitor deadlines. This tool enabled us to divide the project into smaller tasks, assign responsibilities, identify dependencies, and track the status of completion. Key milestones were defined to mark significant stages in the project, such as data source finalization, water-footprint dataset completion, calculation engine implementation, and online deployment of the system.

A Gantt chart usually has tasks displayed vertically and time on the horizontal axis. Each task is represented by a bar that shows its start and end dates. Dependencies are represented with arrows, milestones with diamonds, and progress can be indicated with the use of shaded parts of each bar. This tool helped us make good use of our resources and keep communication clear and coordination strong among the team members throughout the project.

Project Planning

The planning stage was centered around building the project on a solid ground. Activities to be done were identifying system requirements, assembling and refining water-footprint datasets, creating the leading system architecture, and installing the necessary technology stack. To make sure that every major step was done before proceeding to the next development phase, the use of milestones was made.

Table 4.1: Project Planning Timeline

Task ID	Task Name	Start Date	End Date	Milestone	Responsible
P1	Requirement Gathering & Item List Finalization	15-Aug-25	21-Aug-25	Requirements Final	Project Lead

P2	Dataset Collection	22-Aug-25	28-Aug-25	Dataset Ready	Data Team
P3	System Design & Architecture	29-Aug-25	04-Sep-25	Design Approved	Dev Lead
P4	Technology Stack Setup	05-Sep-25	08-Sep-25	Setup Complete	Dev Team
P5	Planning Review & Approval	09-Sep-25	10-Sep-25	Planning Approved	Project Lead

Description: Table 4.1 gives an overview of the planning stage activities, including time frames, key events, and duties. Such orderly planning not only made the development phase of the Digital Water Footprint Calculator to begin with a well-defined pathway but also mitigated risks that came from having partially finished or vaguely defined requirements.

Project Implementation

The Digital Water Footprint Calculator was the central development and deployment project during the implementation phase. The activities performed at that time were: creating a backend calculation engine, incorporating water-footprint datasets, applying the frontend UI/UX, testing, taking user feedback, and deploying to the cloud. Milestones were drawn up for the alpha release, combination of datasets, UI readiness, testing approval, and the last live deployment.

Table 4.2: Project Implementation Timeline

Task ID	Task Name	Start Date	End Date	Milestone	Responsible
I1	Backend Development for Footprint Calculation Engine	11-Sep-25	30-Sep-25	Alpha Version Ready	Dev Team

I2	Water Footprint Dataset Integration	01-Oct-25	10-Oct-25	Integration Complete	Data Team
I3	UI/UX Implementation	11-Oct-25	25-Oct-25	UI Ready	Frontend Team
I4	Testing & Feedback	26-Oct-25	15-Nov-25	Testing Approved	QA Team
I5	Cloud Deployment & Final Launch	16-Nov-25	30-Nov-25	Live Version Deployed	DevOps Team

Description: Table 4.2 showing the order of tasks, milestones, and who is responsible for them. The schedule established by the timeline made it easier to conduct and finish the Digital Water Footprint Calculator project in the stipulated time.

4.2 Risk Analysis

Risk analysis is a crucial step in the process of spotting the internal and external factors that might have an effect on the creation and use of the Digital Water Footprint Analysis System. The PESTLE framework—taking into account Political, Economic, Social, Technological, Legal, and Environmental factors—assists in unearthing the difficulties and advantages linked to the installation of a digital sustainability platform. This method makes possible the proactive development of mitigating measures and, at the same time, strengthens the project reliability, scalability, and environmental impact in the long run.

Table 4.3 : PESTLE-Based Risk Analysis for Digital Water Footprint Analysis System

Factor	Potential Risks Impacting Project Success	Risk Mitigation Strategies
Political	Changes in government environmental or sustainability policies may affect project adoption or funding, and	Project goals will be aligned with national missions such as the National Water Mission and UN SDG guidelines, and collaboration will be

	regulations related to climate reporting or environmental data may require compliance adjustments.	maintained with environmental authorities, academic institutions, and sustainability departments to ensure regulatory compliance.
Economic	Limited financial resources for cloud hosting, dataset licensing, c constraints may affect collaboration with environmental agencies or educational institutions.	Open-source tools, lightweight machine learning models, and cost-efficient cloud platforms will be used, and partnerships, research grants, or CSR collaborations will be explored to support scaling and maintenance.
Social	Low public awareness of water footprints may slow adoption, and users may misinterpret sustainability metrics due to insufficient understanding.	Awareness activities will be conducted to explain water usage and environmental impact, and a user-friendly interface with clear explanations and visual supports will be implemented to improve understanding.
Technological	Model accuracy may be reduced due to incomplete datasets, regional variability, or inconsistent user inputs, and rapid advancements in sustainability modeling may make current methods outdated, while cybersecurity risks may also arise.	Diverse and region-aware datasets will be used with periodic retraining, modular architecture will be adopted to integrate improved estimation techniques or environmental APIs, and secure cloud storage with encryption and regular system maintenance will be implemented.
Legal	Failure to comply with data protection regulations such as GDPR or DPDPA 2023 may result in legal penalties, and users may misinterpret estimation results leading to accountability concerns.	User interactions will be encrypted and anonymized, explicit consent will be obtained with clear disclaimers stating that results are estimates and not exact values, and compliance will be maintained with current data and sustainability regulations.

Envirnomental	High computational energy consumption during model training can increase carbon footprint, and dependence on cloud infrastructure may contribute to indirect environmental impact.	Energy-efficient GPUs and optimized training cycles will be used, cloud providers with sustainability programs such as carbon-neutral data centers will be preferred, and the platform will encourage users to make environmentally conscious choices to reduce water consumption.

The PESTLE analysis uncovers significant external risks and corresponding mitigating measures for the Digital Water Footprint Analysis System. The project, via the aforementioned political alignment, privacy regulations compliance, technological adaptability, and environmental awareness, reinforces its practical viability. The successful execution of these strategies will result in greater user trust, system dependability, and sustainability impact in the long run.

4.3 Project Budget

The Digital Water Footprint Analysis System was completely realized with the help of open-source technologies and campus-based infrastructure, which led to a direct financial expenditure of nothing for the developers. Processing of data, modeling, and deployment of the web were all done in the Department of Computer Science and Engineering, Presidency University's premises.

Table 4.4: Budget Summary for Digital Water Footprint Analysis System

Item	**Resource Used**	**Cost(INR/USD)**
Dataset Sources	Public datasets & research publications	₹0 / $0
Machine Learning Framework	Python + Scikit-learn / TensorFlow (Open-source)	₹0 / $0

Frontend	HTML5, CSS3, JavaScript	₹0 / $0
Backend	Python Flask / FastAPI (Open-source)	₹0 / $0
Training Hardware	University GPU Lab and lab desktops	₹0 / $0
Development Machines	University lab PCs and personal laptops	₹0 / $0
Cloud/Hosting	Free-tier services (Render / Vercel)	₹0 / $0
Version Control	Git + GitHub (Free tier)	₹0 / $0
Domain & SSL	Not required (used *.vercel.app subdomain)	₹0 / $0
Documentation & Printing	University Printers	₹0 / $0

Total Project Cost: ₹0 (Zero Rupees)

The complete execution of the project was done without the use of any paid software, premium cloud services, external datasets, or personal hardware purchases. All the computational and infrastructure resources were provided by the Presidency University GPU Research Lab and the department's facilities, and this was in accordance with the university's policies that support student research through academic resources.

Chapter 5

ANALYSIS AND DESIGN

In system development, the analysis and design phase are separate yet intimately intertwined. The analysis phase aims to get to the bottom of the problem, to do so it will gather the needs and expectations from the users and it will also clarify what the system is to do. It thus answers such fundamental questions as: what is the system's aim? what are the necessary features? what are the limits that have to be taken into account? After that, the design phase takes over and decides the manner in which the requirements will be translated into actual software. It creates a detailed drawing which includes the system architecture, functional modules, data flows, interfaces, and interactions. Simply put, the analysis phase tells us what requirements the system should meet, while the design phase tells us how these requirements will be met. Design is a creative process that involves careful planning and structuring of system components to meet functional goals while taking into account usability, scalability, maintainability, and performance. Through analysis, the problem is dissected into smaller parts, relationships are identified, and possible difficulties or limitations are discovered. At the end of the day, the Digital Water Footprint Calculator through the permutation of analysis and design guarantees users a systematic approach that leads to a solid, precise, and friendly solution to use.

5.1 Requirements

The requirements phase establishes the groundwork for the Digital Water Footprint Calculator project. It delineates the system’s aims, functions, limitations, and non-functional expectations. The requirements are divided into hardware, software, data, management, security, and user interface needs.

5.1.1 System Hardware Requirements

- Identify Initial Conditions: The cloud servers will be the home for the system while the users can access it through web browsers on desktops or mobile devices. An internet connection that is smooth and stable is a must for both the fetching of datasets and the providing of real-time results.
- Determine Input Parameters: The users input names of the items (like rice, cotton shirt, vegetables) and ask for the details regarding water-footprint or reports for comparison.

- System Outcomes: The system has to provide not only the water-footprint values but also breakdown (blue, green, grey water) and sustainability insights tailored to the user.
- Formulate Relations: The user inputs work together with the verified datasets and calculation models to produce output that is meaningful.
- Identify System Constraints: The system has to be able to handle several users at the same time, keep the latency low for fast data retrieval, and make sure the cloud performs efficiently.

5.1.2 System Software Requirements

- **Identify Initial Conditions**: The whole system is based on data processing through Python, backend operations using Flask/Node.js, and frontend interface in either React.js or Angular.
- **Determine Input Parameters**: The inputs consist of item names typed by users, updates of the dataset, feedback sent, and requests for comparison.
- **System Outcomes**: Expected outcomes will be the results of water-footprint calculation, displays in the form of graphs, and reports of sustainable practices that can be downloaded.
- **Formulate Relations**: The backend takes the user inputs, processes them with footprint calculation formulas, gets the database values and finally sends the results to the UI.
- **Identify System Constraints**: Cross-platform compatibility has to be ensured by software, modular code for easy updates, and secure data and datasets handling for users.

5.1.3 Other Requirements

- **Data Collection Requirements**: Very careful gathering of item questions, usage data, and user feedback, so as to enhance correctness.
- **Data Analysis Requirements**: Power processing water-footprint datasets, application of formula-dependent calculations, and bringing to light insights.
- **System Management Requirements**: Admin interface for updates of datasets, system performance monitoring, and user management should be provided.
- **Security Requirements**: Enact the triad of authentication, authorization, and the encrypted storage of sensitive data along with environmental datasets.
- **User Interface Requirements**: Create a user-friendly and fast interface that is accessibl

to both web and mobile users.

Table 5.1: System Requirements for water footprint

Purpose	A digital tool to calculate and display the water footprint of various daily-use items.
Behaviour	The system takes user inputs, gets data-set values and gives the correct blue, green, and gray water-footprint results.
System Management	A control panel for an administrator where he can update datasets, watch system usage, and deal with user feedback.
Data Analysis	Applies the formula for water-footprint calculations and gives sustainability insights on item-wise basis.
Application Deployment	Using cloud servers and can be accessed from anywhere through web browsers on any device.
Security	Comprises user authentication, secure API access, encrypted data storage, and prevention of unauthorized access or data tampering.

Description: Table 5.1 the main requirements appear, among them the system's purpose, behavior, management, data analysis, deployment, and security. Thus, this act as a design guide for both hardware and software keeping the system aligned with user and operational requirements.

5.2 Block Diagram

The system architecture of the Digital Water Footprint Calculator is depicted in Fig. 5.1. The diagram exhibits the data passage from the left side inputs through the center processing modules to the outputs on the right side, thereby, giving a good illustration of the system functioning.

- **Input Block (Left)**: The user supplies all the information in this block, such as the daily-use item’s name (e.g., rice, cotton shirt, vegetables), requests for comparisons, or questions about sustainability. The input block facilitates user inputs validation prior further processing.

- **Processing Block (Middle)**: The heart of the system is made up of the core functional modules, which are data preprocessing, item recognition, retrieval of water-footprint values from datasets, computation of blue/green/grey water usage, and generation of insights based on predefined formulas. The arrows between the modules show the step-by-step flow of data in the system from input interpretation to calculation.
- **Output Block (Right)**: Indicates to the user in what format processed information is presented. This includes item-wise water footprint values, graphical visualizations, comparison charts, sustainability recommendations, and downloadable reports for further reference or analysis.

Description and Suitability:

- A functional module is represented by each block and not by specified hardware, thus the diagram is appropriate for a conceptual understanding of the entire system workings.
- The arrows are a clear representation of the information flow direction from the input to the output.
- The blocks are created in a way that they are different enough from each other thus separating the functions of input, processing, and output, and this is a very good practice in terms of preventing misunderstanding.
- The block diagram is a good way to illustrate the Digital Water Footprint Calculator workflow where by user inputs are transformed into environmental insights. It serves as a very good and easy reference for both the developers and the stakeholders because it makes the system structure very clear and helps the designers to smoothly transition to implementation. Besides, the diagram has also pointed out the main functional areas thus it is easy to spot the dependencies and interactions between the modules.

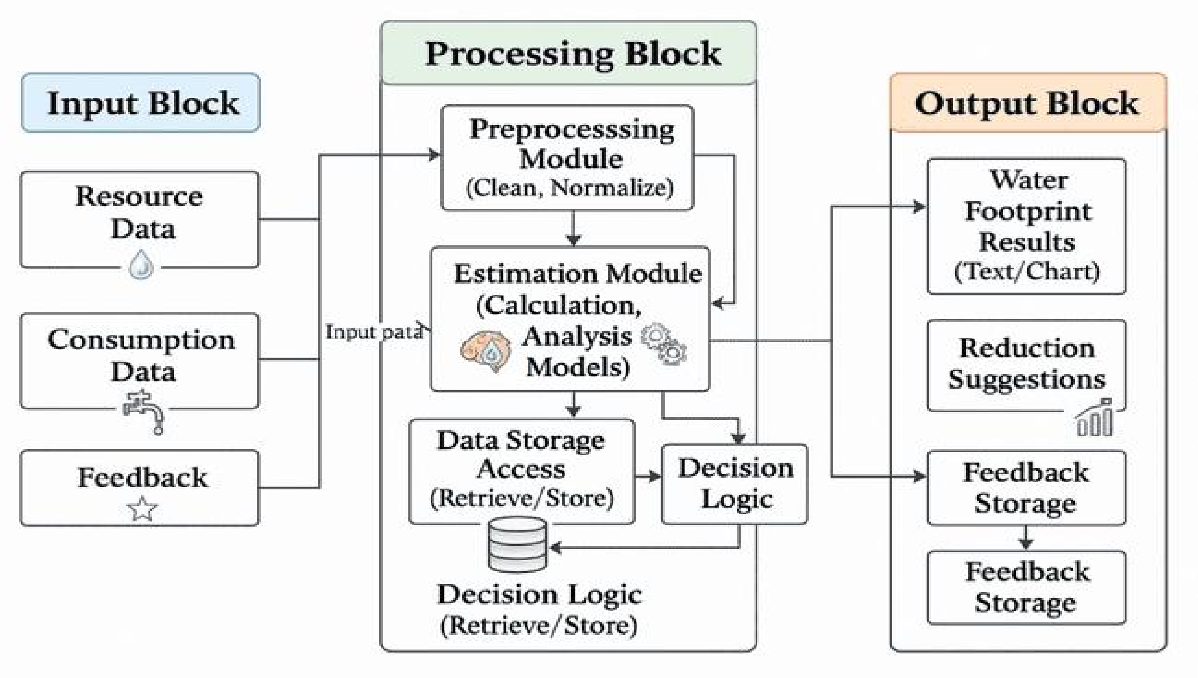

Fig. 5.1:Functional block diagram of the Digital Water Footprint Calculator showing the flow of inputs, processing modules, and outputs.

Description: As shown in Fig. 5.1 shows that the system accepts user inputs including queries about items, and water usage and then these inputs undergo the processes of preprocessing, dataset retrieval, calculation and analysis, and decision logic components before being finally output as water-footprint results, graphical charts, sustainability suggestions, and feedback storage. This representation of the functions presents a simple and easy-to-understand view of the system working and at the same time shows the interaction of various functions within the Digital Water Footprint Calculator.

5.3 System Flow Chart

A system flow chart is a graphic illustration of a system's operations in their order, such as initialization, input, processing, decision-making and output. It aids in comprehending the overall logic and workflow by demonstrating the movement of data from the starting point to the final results. In the case of the Digital Water Footprint Calculator, the flow chart depicts a gradual process of user query receipt through water-footprint value calculation and delivery. This offers a transparent view of the system, developers' and stakeholders' understanding of behavior, computation flow, and decision-making logic.

Flowchart Description

- **Start / Initialization**: Initially the system initiates the server-side of the app, loads water-footprint datasets, and preps the calculation engine to do the work of conversion.
- **Input Stage**: The users will introduce the name of an item they use daily (e.g., rice, cotton shirt), ask for comparisons or give feedback. Checks will be done by the system to ensure that the inputs are correct and complete.
- Processing Stage:
- **Preprocessing**: The user input is cleaned and standardized to correspond to the dataset formats. Item Identification: It is figured out by the NLP/ML process whether the input item is in the database or alternative suggestions are needed.
- **Calculation / Analysis Module**: Post fetching water-footprint values from datasets, formulas are applied to compute blue, green and grey water usage.
- **Decision Logic**: The system decides which output to show—single item footprint, comparison chart, sustainability insight, or error message.
- **Decision Points**: The system analyzes the situation for various problems like missing item names, items not in the database, wrong formats, or partially entered inputs. If the issues are not resolved, suitable prompts or recommendations are generated.
- **Output Stage**: The outputs that the system provides after processing and making decisions include: Water-footprint results per item, Charts (bar/line/pie) for visual representation, Water usage reduction suggestions, Note of user's opinion for next enhancements.
- **End / Termination**: The process finishes as soon as the answer is given and the input is stored, with the system being set for the next query.

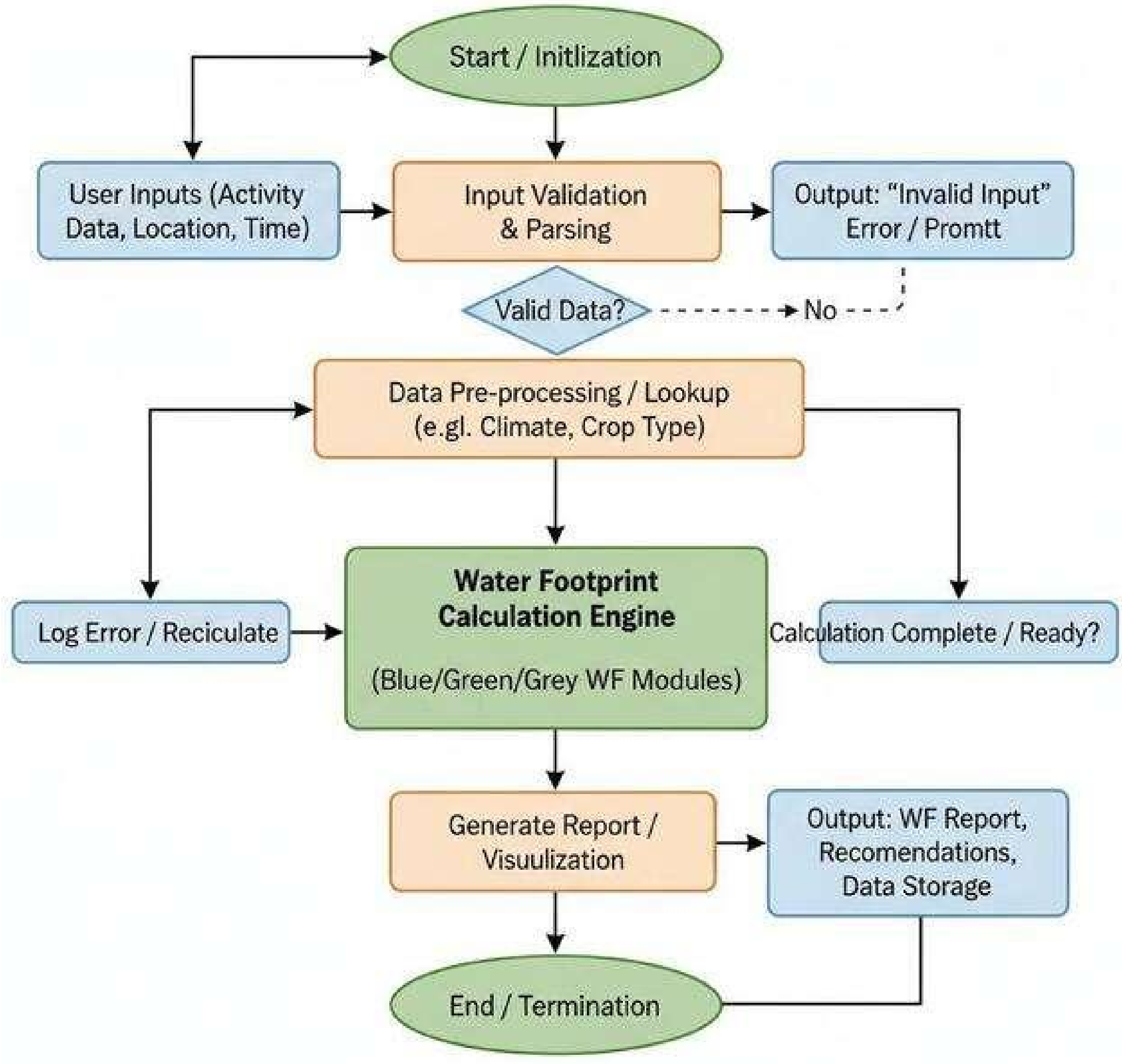

Fig. 5.2: System flow chart of the Digital Water Footprint Calculator showing the sequence from initialization, inputs, processing, decision-making, to outputs.

Description: Fig. 5.2, The Digital Water Footprint Calculator depicted in Fig. 5.2 is built on a systematic workflow that starts with the initialization of the system, goes through the validation of inputs, and then the preprocessing of user queries. Next, the system recognizes the chosen item, gets water-footprint data, carries out the calculation via analytical modules, and applies decision-making logic. Outputs like water-footprint values, visual charts, and sustainability proposals are the ones the system provides at last. This flow chart is a great tool for visualizing the system logic clearly, thus assisting the developers and the stakeholders in grasping the operational flow and the handling of edge cases.

5.4 Choosing Devices

The Digital Water Footprint Calculator project is composed of an entirely software-based system that is hosted on a cloud infrastructure. As there are no physical sensing or IoT components in the project, hardware components like microcontrollers, sensors, or actuators are not necessary. What is needed instead is to choose the right server infrastructure, database engines, and software libraries which will provide accurate water-footprint calculations, high-speed processing, and easy scalability.

Server / Cloud Envirnoment

The JobSathi system supports a cloud server for the whole backend, processing the NLP/ML queries, and saving the user data. The recommended specifications are as follows:

- RAM: 8GB or more – so that operations on datasets and interactions by several users at the same time can be handled really well CPU: Quad-core or more – very fast computation of footprint values and instantly getting the API response.
- Storage: SSD storage of at least 100GB – for keeping datasets, logs, and reports produced.
- Operating System: Linux-based servers, for example, Ubuntu 20.04 LTS – stable, secure, and has good compatibility with both Python and backend services.

Database Engine

The water footprint calculator is utilizing environmental datasets and user activity logs, which call for an efficient storage and retrieval. Recommended database systems are:

- MySQL: Perfect for structured datasets including item names, water usage values, and calculation metadata .
- MongoDB (optional): Good for the storage of semi-structured data like logs, user queries, or system events

Required Software Libraries

Backend calculations, data processing, and user interface development are supported by a number of software libraries and frameworks.

Python Libraries:

- pandas, NumPy – computations of water-footprint and carrying out operations on dataset.
- Flask / FastAPI – minimalistic back-end frameworks for exposing APIs.
- Matplotlib / Plotly – creating visual representations of water consumption in charts and graphs.

- SQLAlchemy / PyMySQL – linking up with database and object relational mapping.

Front-end Libraries:

- ReactJS / Angular – rich, interactive UI development.
- Bootstrap – aesthetic and adaptive design.

Optional API Services:

The system can be made smarter and the user experience improved by using the following

- APIs: Visualization APIs – sophisticated charting and reporting.
- Dataset Update APIs – seamless connection with environmental or sustainability databases.
- Email / Notification APIs – delivering footprint reports and usage summaries.

Description / Suitability:

Cloud infrastructure and contemporary software libraries selection have been made in a way that the Digital Water Footprint Calculator functions well, and at the same time, user requests are supported and datasets are processed with precision. As the system relies only on software, this strategy not only removes the requirement for hardware but also lowers the costs of operation and makes it possible to scale up or down easily according to the dataset size or the number of users.

5.5 Designing Units

The Digital Water Footprint Calculator is organized into different software modules for system management, development facilitation, and correct user input processing with high efficiency. Every module is dedicated to a certain function and combined they create an integrated system that accepts user queries, pulls data sources, does calculations, and produces water-footprint insights.

Software Modules / Units

1. Input Module

- Interacts with users and gathers information like product names (for instance, rice, cotton shirt) or requests for comparisons.
- Checks and cleans the user inputs to make sure the item is correctly formatted and can be identified in the dataset.

Avoids passing on unprocessed or wrongly processed inputs to the next stage.

2. Item Detection / Matching Module

- Detects if the item given by the user is present in the water-footprint database.
- Sends valid items to the calculation module while directing invalid items to the suggestion module.
- Guarantees perfect matching of user inputs with the terminology used in the dataset.

3. Data Processing / Calculation Module

- Calculates the water footprint of the products using a set of environmental data.
- Gathers and processes the blue, green, and grey water amounts for each item.
- Uses equations to derive the water footprint for one unit in total.
- Guarantees effective management of various user inquiries that happen at the same time.

4. Decision Engine

- The calculation module's outcome is evaluated to find the appropriate output type.
- The choice of a show case consisting of only one footprint, comparison output or recommendations is made.
- The reasonings and responses of the system are very logical and are also aware of the context.

5. Output Module

Displays results in a clear and interactive format.

Generates:

- Water footprint values (blue/green/grey)
- Charts and graphs
- Sustainability suggestions
- Comparison results
- Formats output for readability on both desktop and mobile interfaces.

Functional Block Diagram / Data Flow

The functional blocks symbolize software parts instead of actual hardware components. Data transfer etween the modules is as shown below:

User Input → Item Matching → Calculation Module → Decision Engine → Output

(Values / Charts / Suggestions)

- Arrows show data flow direction.
- All modules communicate using internal APIs or calls to functions.
- Modular architecture will permit future improvements like extra data sources, novel product categories, or sophisticated analytic models to be incorporated into one module without impacting others.

Suitability for the Project

Arranging the system in this way with the software units brings the following advantages:

- **Clarity:** There is a clear and specific responsibility for each module.
- **Maintainability:** One can update the modules without affecting the rest.
- **Scalability:** Future enhancements of, for example, new datasets or better calculation methods, are supported.
- **Efficiency:** The data flow has been made more efficient, leading to shorter processing times and a more responsive system.

5.6 Standards

The Digital Water Footprint Calculator project makes it necessary to follow the relevant software, data, and communication standards in order to guarantee accuracy, interoperability, security, and prompt data transfer. As the system is entirely based on software and does not include IoT devices, just software and data standards are implemented.

Key Standards Implemented

1. Communication Protocols

- **HTTP/HTTPS:**
  Facilitates secure and encrypted communication between frontend and backend.
- **REST API:**
  Enables the execution of structured request-response operations for getting dataset values and performing footprint calculations.

2. Data Formats

- **JSON:**
  This is the format that is mainly used for data interchange between the backend APIs and the user interface.
- **CSV / XML:**
  These are the formats that are used to carry out dataset import, export, and updating of water-footprint values from external environmental sources.

3. Security Standards

- **TLS/SSL Encryption:**
  This kind of encryption provides security to the communication that takes place between the users and the cloud server.
- **Authentication & Access Control:**
  This mechanism safeguards critical user data and blocks unauthorized alterations to the system.
- **Secure Coding Practices:**
  Developers adopt secure practices to prevent vulnerabilities like injections or data tampering.

4. Software Development Standards

- **PEP 8 (Python):**
  The standard provides a way to maintain a uniform coding style which is readable and, at the same time, easy to maintain in backend scripts.
- **Modular Design Principles:**
  The system is divided into different modules—input, item matching, calculation engine, and output—which can be individually updated and tested.
- **Version Control (Git):**
  This helps in monitoring changes made to the code and promoting teamwork among developers.

Benefits for the Water Footprint Calculator

- **Improved Security:**
  Guarantees that the system's integrity and the user's data are protected during the calculation and visualization process.
- **Better Interoperability:**
  Provides a guarantee of uniform behavior over all browsers and devices.
- **Efficient Data Management:**
  Environmental datasets become more accessible for updating and expanding thanks to the use of standardized formats.
- **Reduced Development Effort:**
  Adoption of best practices accelerates the processes of coding, testing, and scaling.

Image / Diagram Suggestion:

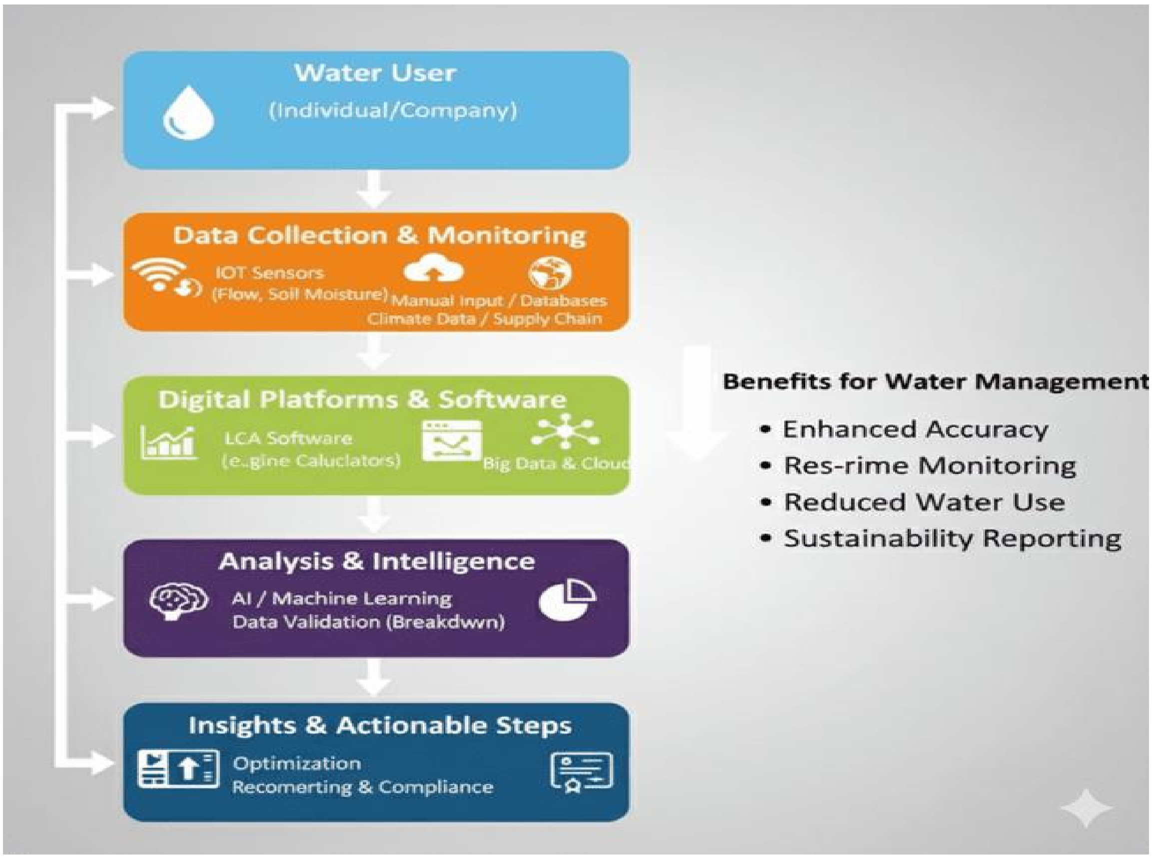

Fig 5.3**:** Overview of software standards in the Digital Water Footprint Calculator, illustrating data flow from user to application and Highlighting communication, security, and data.

5.7 Mapping with IoTWF Reference Model Layers

The IoT World Forum (IoTWF) Reference Model, which presents a seven-layer architectural framework, is frequently used to illustrate and explain IoT systems. In this regard, even though the Digital Water Footprint Calculator is not an IoT system per se, and it does not operate with sensors nor embedded devices, still, mapping it onto the IoTWF model will enable us to decompose the system into logical layers, pinpoint data flow through the architecture and demonstrate the security measures taken at every particular step. The layer mapping has also been used to clarify interoperability, modularity, and future expansion, especially in the case where real-time environmental data or IoT-based water tracking would be integrated in the future.

The IoT World Forum Reference Model

- Demonstrates the seven layers spanning from physical devices to collaboration and business processes.
- The flow of data is represented by arrows which show the movement from user devices upward to the processing and application of data.
- Across several layers, the enforcement of security measures is applied in order to guard datasets, user queries, and server resources.

Table 5.2 Mapping Water Footprint Calculator Layers to IoTWF Reference Model

IoTWF Layer	Project Layer Mapping	Security / Notes
Collaboration Processes	The interpretation of user results, sustainability recommendations, and report generation.	Control of access for the user-specific comparison data handling.
Application	An online platform showing water footprint values, graphs, and sustainability insights.	Results access is secured by HTTPS/SSL.
Data Abstraction	Raw dataset values	Validation of data to hinder

	(blue/green/grey water) are converted into calculation inputs by backend modules.	manipulation or incorrect inputs.
Data Accumulation	Data Accumulation Storage of item datasets, logs, historical queries in the database.	Encrypted storage, regular backups.
Edge Computing	Validation and normalization are done as light preprocessing of inputs before sending them to the core calculation module.	Request throttling and input sanitization.
Connectivity	Internet communication is established between the user interface and cloud server APIs.	Encrypted data transmission using TLS/SSL.
Physical Devices & Controllers	The user devices such as mobile phones, tablets, or laptops that are used to access the web tool.	Secure login sessions and device-level authentication where applicable.

Suitability for the Water Footprint Calculator:

The Digital Water Footprint Calculator, when referenced against the IoTWF framework, opens up the system's architecture in the most lucid and organized way. The model assists in tracing the data right from the user's front-end through the back-end processing, database, and finally the outputs like footprint values and visual charts. A module-centric layered strategy allocates duties correctly thus making it easy to manage and increasing the system's capacity. Moreover, certain layers—like those involving connectivity, storage, and application access—are made secure thus guaranteeing both users' security and integrity of data. This approach not only allows for future improvements to be integrated easily, e.g., real-time water consumption data or IoT sensors, but also it does not impede the existing system architecture.

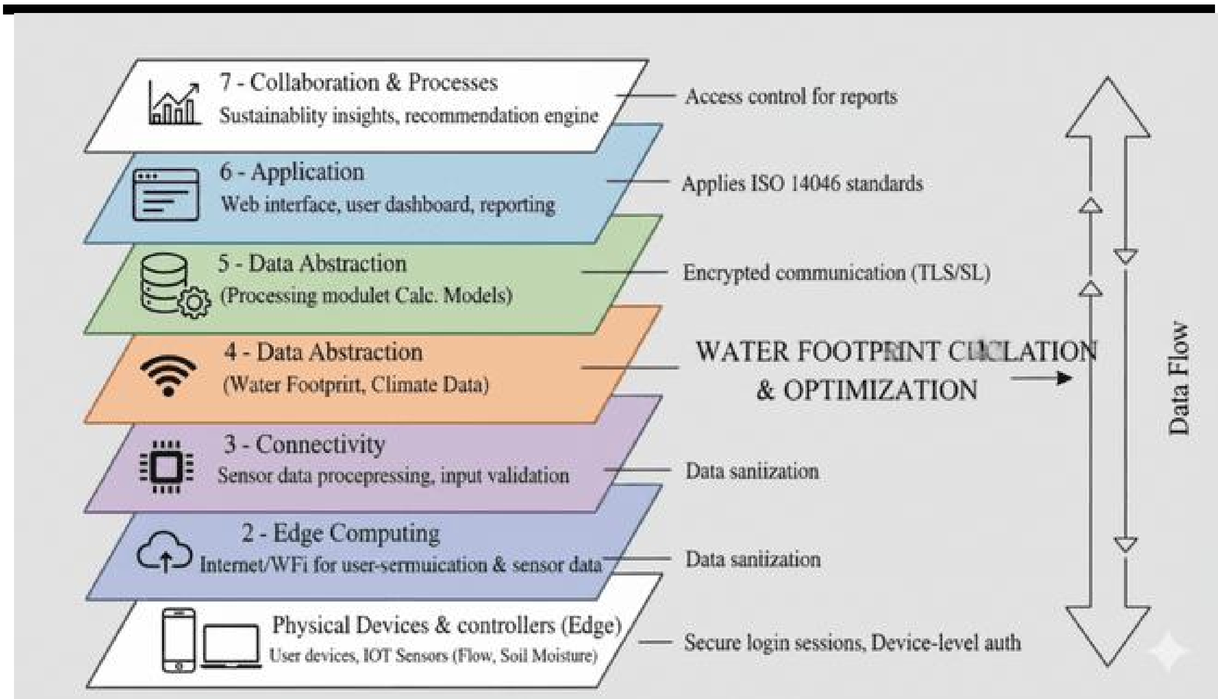

Fig 5.4**:**Water Footprint Calculator system mapped to IoTWF layers, showing module mapping, data flow, and security checkpoints.

Every single layer is equipped with text labels that explain various modules of the Water Footprint Calculator, including user devices, secure connectivity, preprocessing engine, cloud database, calculation models for water footprints, application UI, and sustainability reporting mechanisms.

5.8 Domain Model Specification (Water Footprint Calculator)

The domain model of the Water Footprint Calculator gives a high-level conceptual perspective on the functioning of the system. It points out the major entities, objects, and digital resources that are involved in the water footprint calculation and depicts the interaction of these components. The domain model, therefore, revolves around user inputs, analytical modules, and cloud resources as this system is software-based and uses digital data sources instead of physical IoT devices.

Domain Model Entities for the Water Footprint Calculator

1. Physical Entity

- The physical entities in the project comprise user devices like smartphones, laptops, and tablets.
- The users of these devices can enter item names (for instance, rice, cotton shirt), ask for

- comparisons, and see the resulted water footprints and the harvested sustainability insights.

2. Virtual Entity

- It stands for the digital analogue of the user's physical device.
- A virtual session that keeps temporary data such as selected items, language preference, comparison type, and previous queries is generated for each user interaction.
- Virtual entities make sure that there is no interruption in the process of calculation and reporting.

3. Device

- Devices are the software interfaces through which the system can be interacted with.
- The Web browsers, responsive web application, and Mobile interface are the examples of such.
- These devices serve as the entrance for gathering user input and for exhibiting the computed water footprint results.

4. Resource

- The Water Footprint Calculator has resources that are both on-device and cloud-based: On-device resources include input validation scripts and local session storage.
- Network/cloud-based resources comprise the water footprint database (global and regional datasets), climate and agricultural datasets (optional extension), calculation models (ISO 14046-aligned), multilingual support APIs or external dataset fetching.
- These resources empower precise computation, data extraction, and handling of user inquiries.

5. Service

- Services carry out the necessary computations and data retrievals for estimating water footprint.

The most important services are:

- Item Processing Service Determines whether the item is a food, textile, or product.
- Water Footprint Calculation Service
- Uses equations and data to figure out how much blue, green, and grey water is needed for a particular item.
- Comparison Service Creates comparisons between items or summaries of categories.

- Report Generation Service Provides systematic outputs like daily/weekly footprints or recommendations for more sustainable practices.
- Services act as intermediaries connecting user inputs, resources, and the final outputs.

Suitability for the Water Footprint Calculator

The domain model provides a clear and logical system structure by: the establishment of relations between users, data resources, and processing services; supporting modularity, thus facilitating easy updates to datasets or calculation models; improving maintainability because of the separating of each function into distinct entities; allowing future scalability (e.g., region-wise footprints, crop-specific climate data); and so on. This eventually leads to the developers' and stakeholders' better understanding of the whole system, thus making it possible to have an efficient and well-structured architectures.

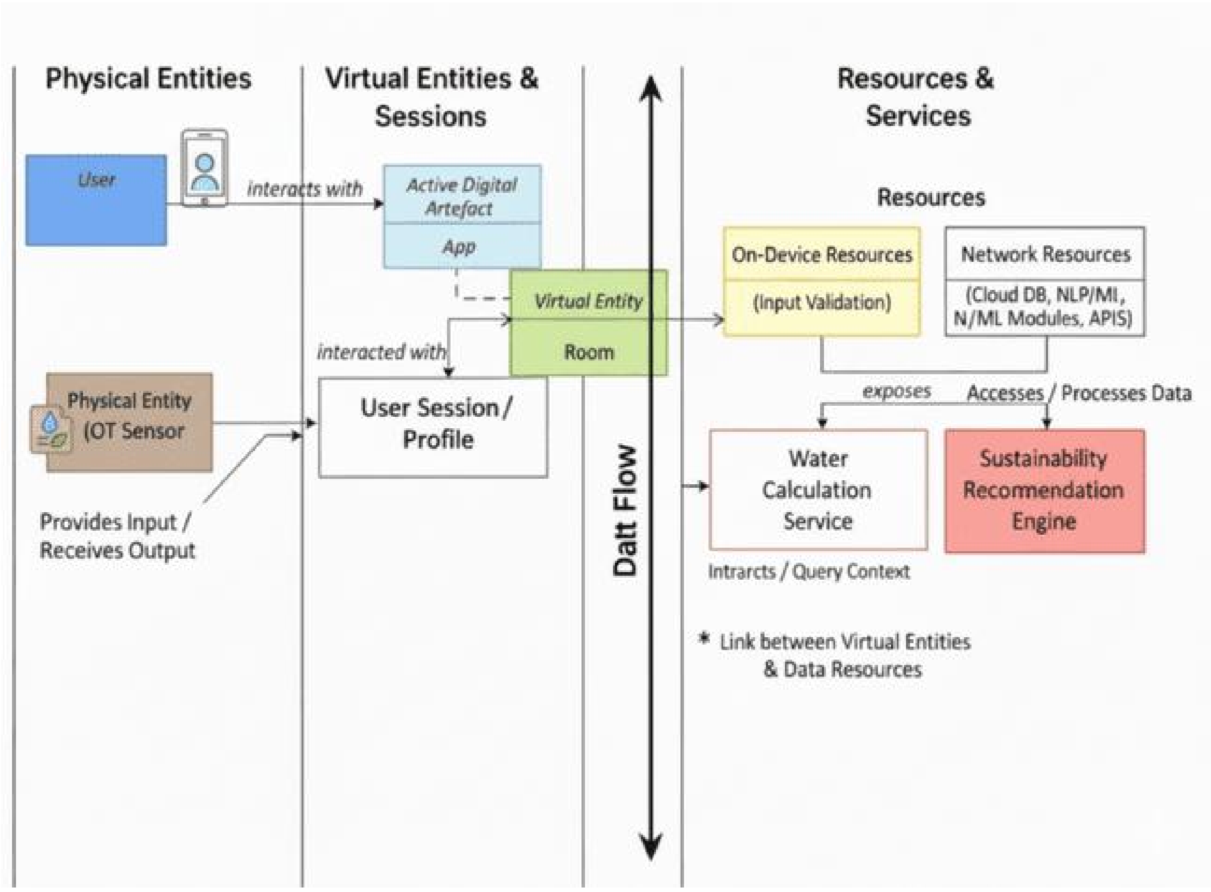

Fig 5.5: Water Footprint System Domain Model: Illustrating interactions between Physical Entities, Virtual Entities, and core Resources & Services for water management.

5.9 Communication Model (Water Footprint Calculator)

The Water Footprint Calculator system needs seamless and efficient communication between the users and the platform to complete activities like item name entry, requests for comparisons, and getting water-footprint calculations and supporting these operations the Request–Response communication model is the best option.

How the Communication Model Works

1. **User-Request:**
   The user sends a query, such as entering an item name (e.g., “1 kg rice”, “cotton shirt”) or asking for a comparison.
2. **Processing Stage:**
   The request reaches the server, it checks the input, and then uses the calculation engine, datasets, and analytical modules to process it.
3. **Immediate Response:**
   After processing, the system returns water footprint value, category breakdown (blue, green, grey water), or comparison results.

Why This Model Is Ideal

The Request–Response model underpins synchronous communication, guaranteeing that no user request is left unanswered without a direct and prompt response. This is a crucial aspect of an interactive calculator where instant results are the main factors in usability and overall user satisfaction improvement. Other communication models such as Publish–Subscribe or Push–Pull are meant for asynchronous or real-time sensor-based systems, which are not the case with the present version of the Water Footprint Calculator.

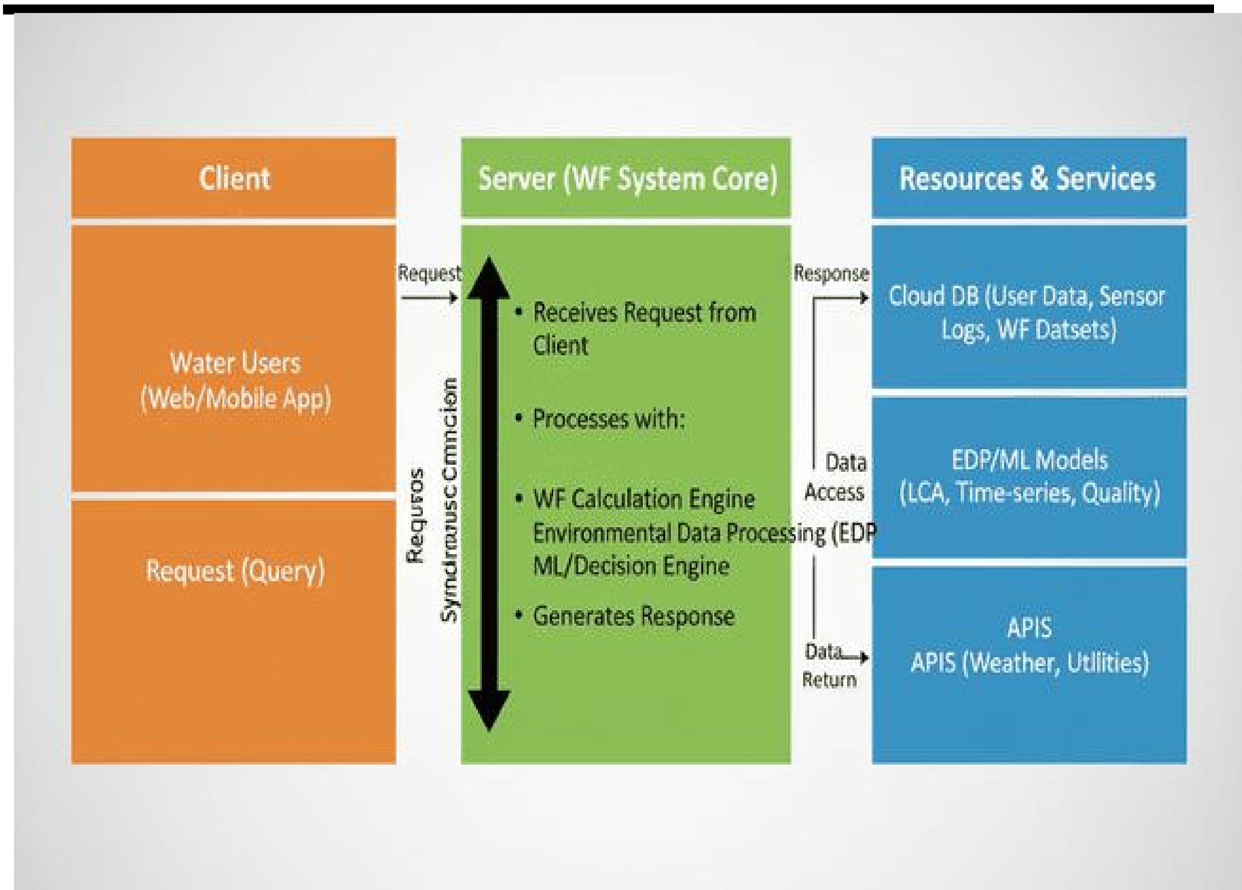

Fig 5.6: Request-Response communication model of the Water Footprint System, illustrating the processing of user requests through the integration of environmental data, IoT inputs, and the quick delivery of sustainability results in real time.

5.10 IoT Deployment Level

Water Footprint Calculator is a cloud-based digital system that calculates, compares, and analyzes the water footprints of various daily-use items. The project does not utilize physical IoT devices or sensors, but its architecture is characterized by IoT Deployment Level 3, where multiple user points connect to a central cloud server for data processing and response delivery. At this level of deployment, user devices function as clients that send item queries to a central computing system, thus making the overall structure similar to IoT-based centralized architectures.

Deployment Overview

User Devices Accessing the web-based calculator can be done using smartphones, laptops, or tablets. These devices relay server queries containing item inputs (e.g. "1 kg rice", "cotton shirt") or comparison requests.

Processing A centralized cloud server is responsible for:

1. Processing the input
2. Validating the input
3. Retrieving the dataset values
4. Performing water footprint calculations (blue, green, grey water)
5. Applying comparison logic
6. Generating sustainability suggestions
7. The server also takes care of maintaining databases and logs.

Output: The user devices receive the processed results as follows: The values of water footprint, Graphs and visuals, Tables for comparison, Reports on sustainability.

Advantages for the Water Footprint Calculator

- **Scalable and Efficient**

A single cloud server provides centralized support for multiple users simultaneously, guaranteeing uninterruptible performance even with the increasing size of the dataset.

- **Centralized Maintenance**

Updates to datasets, algorithms, or UI are done on the server side, providing all users with immediate improvements.

- **Enhanced Security and Privacy**

Critical user interactions (for example, stored preferences or history) are made secure by means of centralized encryption and server security controls.

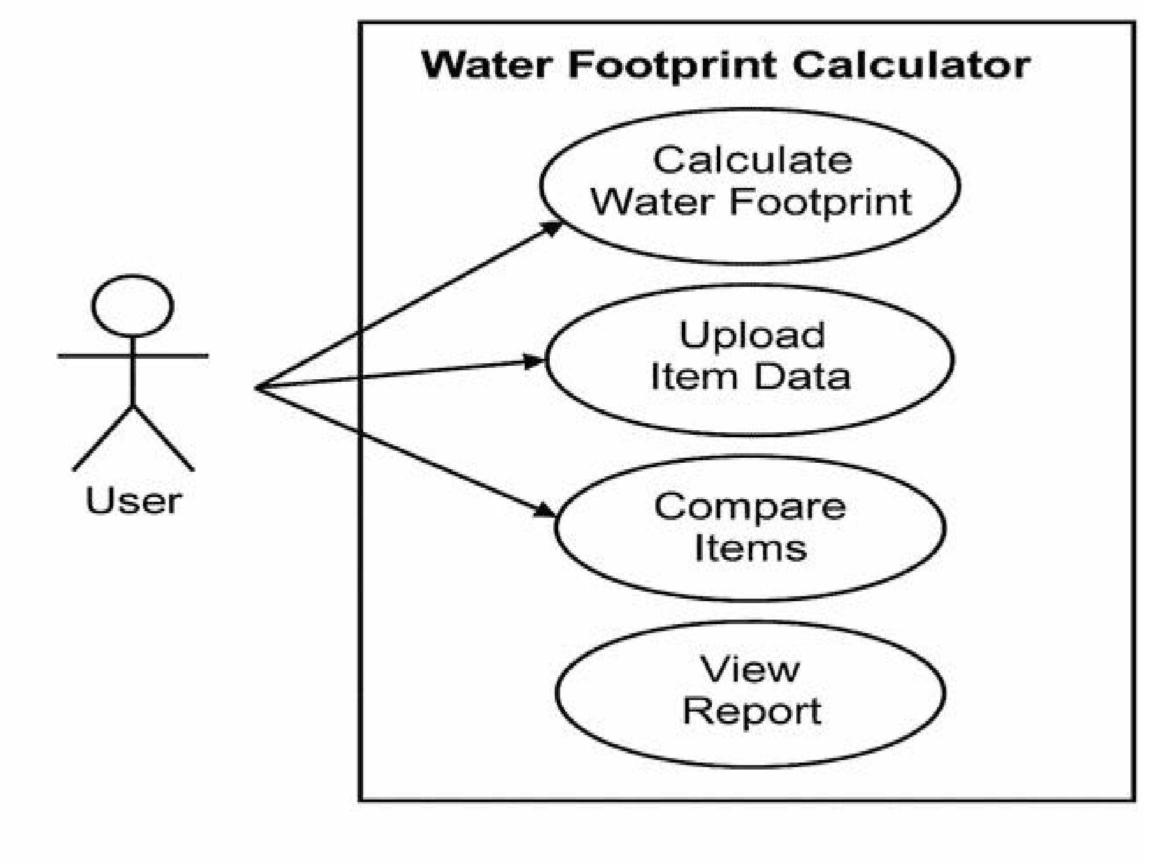

Fig 5.7: The use case diagram for the Water Footprint Calculator illustrates the user-system interactions that include entering item details, validating inputs, calculating footprints, comparing items, and generating final reports.

5.11 Functional View (Water Footprint Calculator)

The functional view of the Water Footprint Calculator sorts the operations of the system into distinct groups, which clarifies the interaction of each module with core concepts and data defined in the domain model. Even though the Water Footprint Calculator is not a physical IoT system, it is still software-centric, yet the concept of functional grouping still applies to separate the modules responsible for different tasks clearly.

Functional Groups and Their Roles:

- **Device / Client Interface:** The interface takes care of the user inputs from web browsers or mobile applications. It accepts item names, quantities, and requests for comparison.
- **Communication:** The management of the client devices interaction with the central cloud server followed a request-response model to guarantee real-time feedback.

- **Services / Processing Modules:** It encompasses input validation, item classification, water footprint computation, and comparison logic. The input data is processed and outputs such as blue/green/grey water values and sustainability insights are provided.

- **Management:** Controls the system operations, user sessions, and workflow management to ensure that tasks are done smoothly.

- **Security:** Manages authentication (if enabled), data privacy, and access control to safeguard user information and uphold dataset integrity.

- **Application / Output:** Transfers processed results to users via reports, dashboards, charts, and footprint summaries.

This type of grouping based on functionalities makes it so that every component of the system has a specific function assigned, which in turn leads to easier and quicker maintenance, better scalability, and clearer operations. The functional perspective also favors similar to the modular approach which permits different modules or groups to work separately but to get integrated smoothly. By splitting the operations into different layers like input handling, communication, processing, management, and security, the Water Footprint Calculator makes sure that the data travels quickly from the user's device to the calculation engine and back. This organized flow not only enhances the reliability of the system but also allows for modular improvements, meaning that new features like more item categories, regional datasets, or visualization tools can be integrated without interfering with the already existing functionality

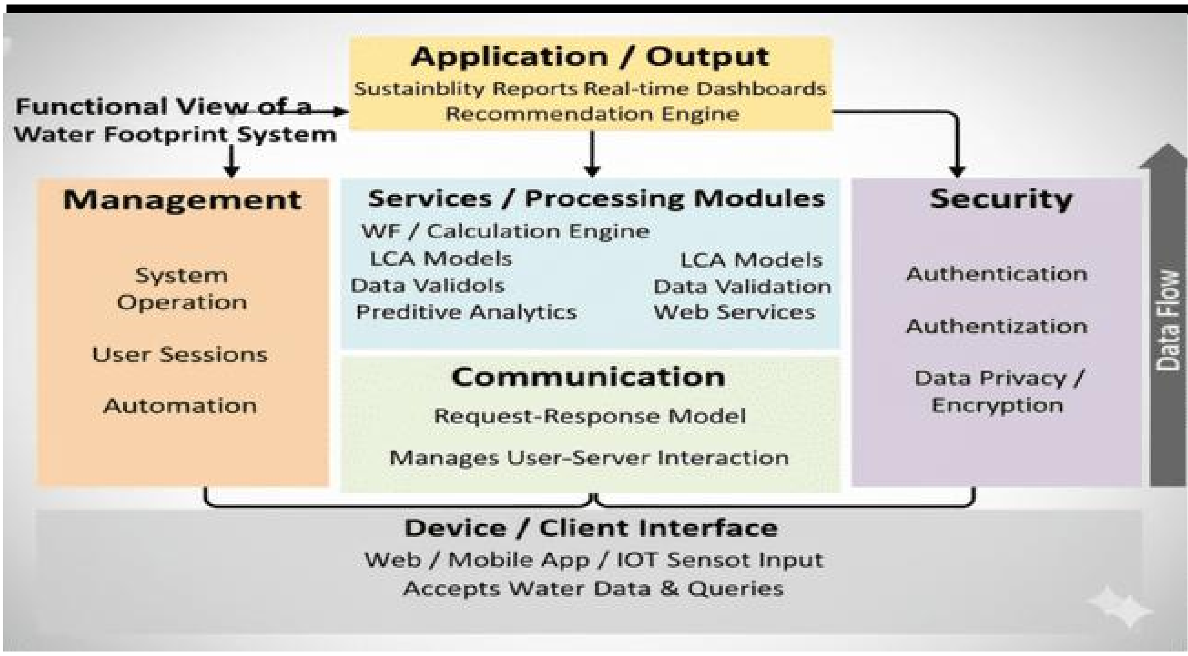

Fig 5.8: Water Footprint Calculator's functional perspective showing user inputs passing through communication, processing, management, and securing modules eventually resulting in water footprint and report outputs.

5.12 Mapping Deployment Level with Functional Blocks (Water Footprint Calculator)

The Water Footprint Calculator has a feature that maps the IoT deployment levels to the different functional groups. This way the interaction between the system components and the location of each functionality in the architecture will be pictorially shown. The system, although software-based and not relying on the physical IoT devices, permits the analogy of IoT deployment for the visualization of the data flow, computation, and responsibility traversing.

- **User Devices (Client Layer / Level 1):** The input module which captures user item entries, quantities, and comparison requests is located at this layer.
- **Connectivity Layer (Level 2):** The communication modules control the data exchange between the client devices and the centralized cloud server via secure HTTPS connections.
- **Edge / Processing Layer (Level 3):** Main actions—which are entering data, identifying categories, and calculating water footprint (blue/green/grey water values)—take place at the server that is central and where the processing power is located.

- **Data Abstraction and Accumulation (Levels 4 & 5):** The cloud database holds the data that has been processed while the aggregation and analytical functions are creating the footprint results, comparisons, and sustainability insights.
- **Application Layer (Level 6):** The output modules provide the results to the user devices through various formats such as charts, reports, tables, and visual summaries.
- **Collaboration & Management Layer (Level 7):** It is responsible for managing workflow, monitoring the system, updating datasets, and ensuring overall security to guarantee smooth and consistent operation.

Through this mapping, it is certain that every functional block corresponds to the right deployment layer which keeps the system to be modular, scalable and easy to maintain. This mapping also illustrates that security and management components cover several layers in order to secure data integrity and provide reliable operation.

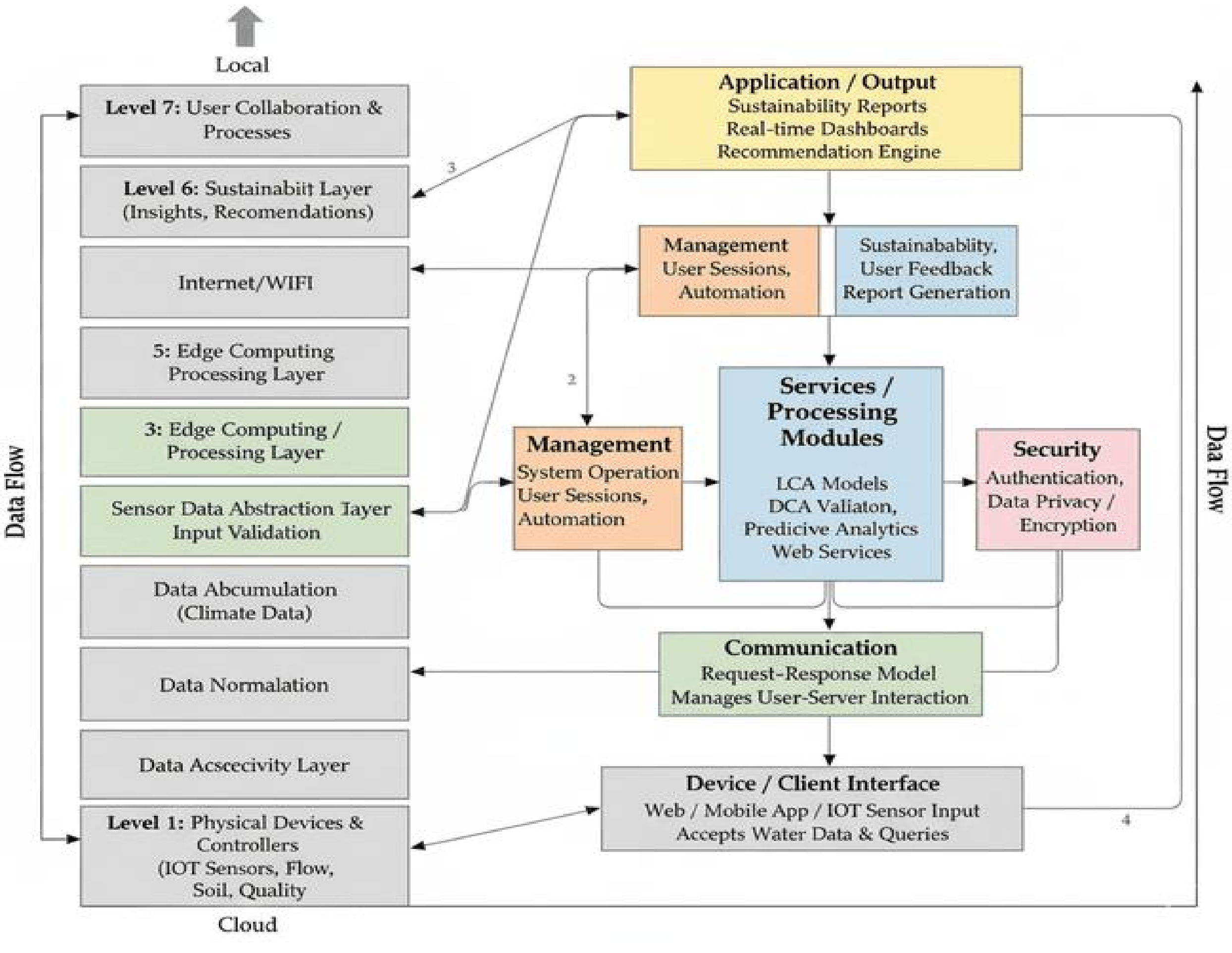

Fig 5.9: The Water Footprint Calculator's functional blocks have been mapped to the levels of IoT deployment, indicating the organization of input, processing, storage, and output

modules across layers for scalability, accuracy, and secure operation.

5.13 Operational View

The operational aspect of the Water Footprint Calculator provides a clear picture of how the entire system is working with its various parts and how it guarantees excellent service delivery. It indicates the communication protocol used by the different modules, services' location, data storage, and user interaction with the system. This perspective is essential for comprehension of system deployment, reliability, and scalability.

Key Operational Components:

- **Service Hosting:** As the current cloud server allots the water footprint calculation and comparison modules the same major services as classification, this fact enables a central maintenance and scalability.

- **Storage:** A cloud-based database houses item datasets, water footprint values, calculation logs, and analytics data. Proper storage, through management provided by the cloud, gives the speed of access and security.

- **Device Options:** Laptops, tablets, or smartphones are the different devices through which users reach the system. The request-response communication model considers these devices to be clients.

- **Application Hosting:** The web interface and backend server are responsible for the entire process from user interactions, sessions to outputs which include footprint values, comparison charts, and sustainability reports.

- **Optional Considerations:** Automated backups, monitoring dashboards, and logging services are the factors that enhance reliability and enable breakthroughs in tracking system performance, dataset updates, and errors.

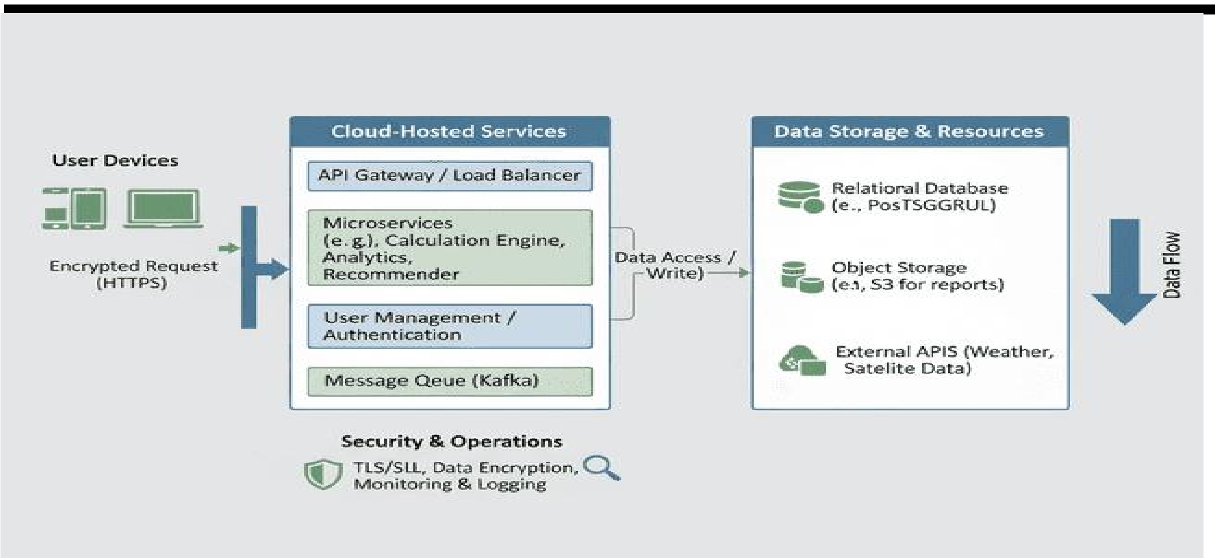

Fig 5.10: A clear and comprehensive operational view of the Water Footprint Calculator that displays interactions between the cloud-hosted services, database storage, and user devices as well as the secure and efficient operation they provide.

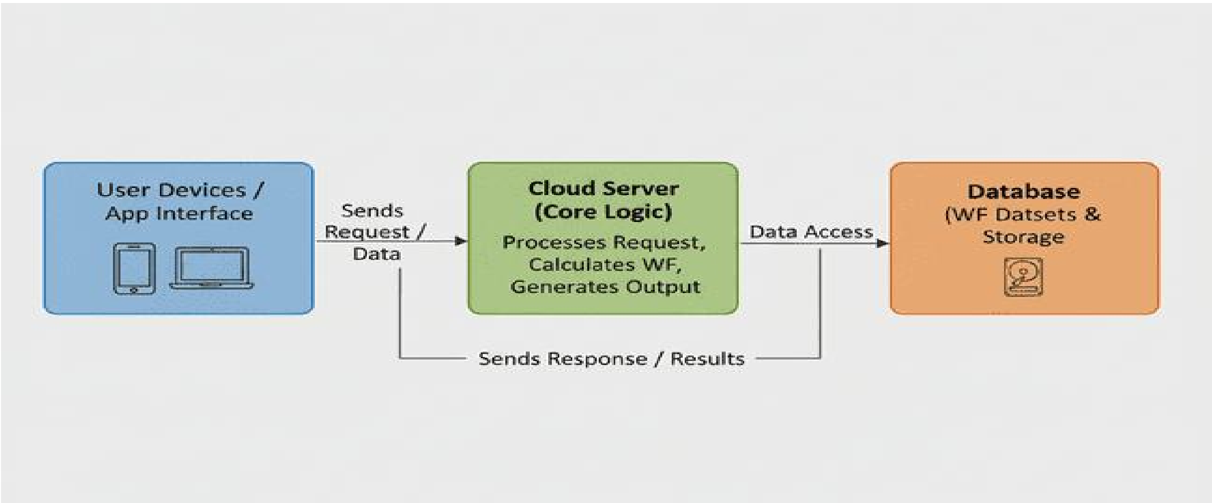

Fig 5.11: A reduced model highlighting just the essential parts—the user gadgets, cloud server, database, and app interface—to point out the main data transfer in the Water Footprint Calculator.

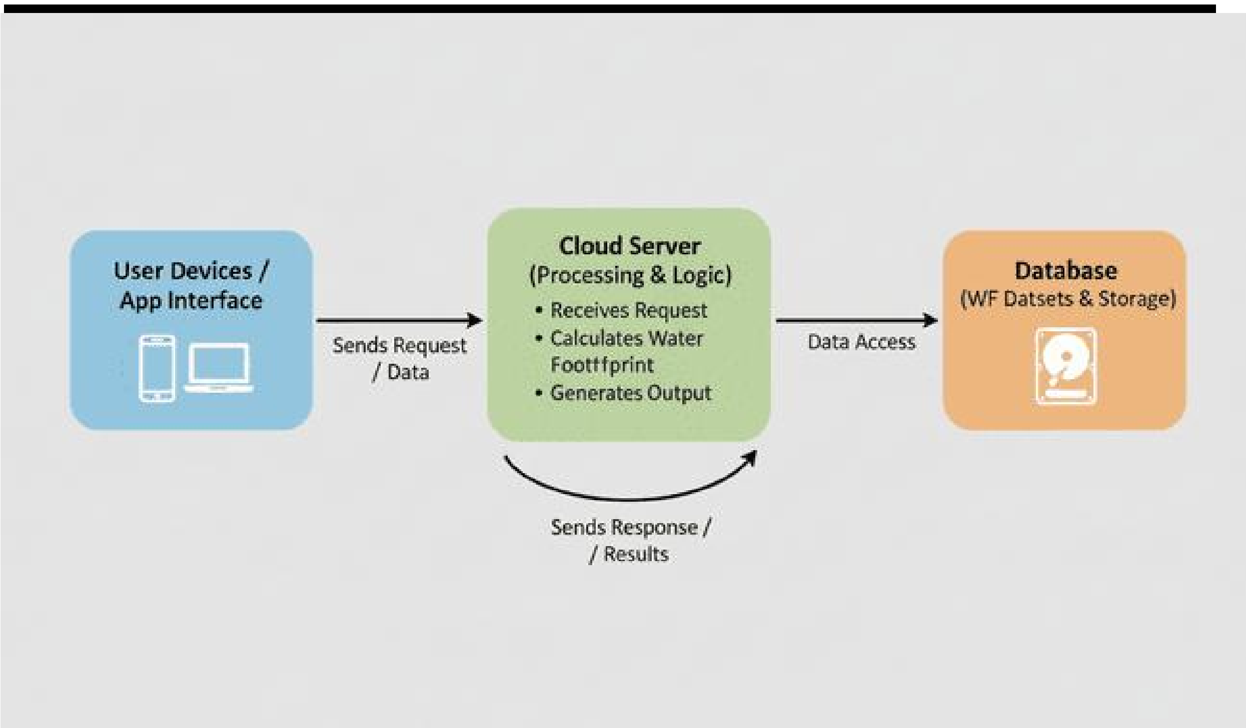

Fig 5.12: Simplified operational view highlighting essential interactions between user devices, the cloud server, and the database in the Water Footprint Calculator.

5.14 Other Design Aspects

The other design aspects in the Water Footprint Calculator are completely software-oriented and they guarantee that every module and service operates at peak efficiency while having smooth interactions with the other components. This aspect covers the workflows, data structures, and services that are the core of the application.

5.14.1 Process Specification

The process specification sets out the complete workflow for each module starting from user input reception to the delivery of water footprint results. Among the key workflows are the following:

- **Input Module Workflow:** Takes care of the user inputs like item names, quantities, and comparison requests, and also does some initial validation.

- **Item Identification Workflow:** Identifies the user-entered item and associates it with the corresponding water footprint dataset.

• **Calculation Workflow:** Calculates the blue, green, and grey water values digitally by using the stored datasets and the calculation rules.

• **Comparison Workflow:** Uses formulas and evaluation logic to compare the water footprints of the selected items.

• **Output Module Workflow:** Presents the results in the form of numbers, charts, or downloadable reports in the user's preferred format.

5.14.2 Information Model Specification

The information model establishes the data structures and connections among the various objects in the system. The main components are as follows:

• **Item Profiles:** They hold basic information, the item's category, and the corresponding footprint values that have been predefined for the different items.

• **Calculation Objects:** They are organized forms of footprint calculations including the water components of blue, green, and grey.

• **Comparison Records:** They are objects that keep metrics, rankings, and sustainability insights of a comparison between two items.

• **Analytics Data:** It includes user statistics, system performance measures, and logs about user interaction for the purpose of improving the system.

5.14.3 Service Specification

The service specification describes the APIs and software services that support the Water Footprint Calculator:

The service specification describes the APIs and software services that support the Water Footprint Calculator:

• **API Endpoints:** RESTful APIs responsible for submission of input, retrieval of items, calculation of footprint and generation of output.

Calculation Services: Hosted applications that perform mathematical processing, access to datasets and calculation of water footprint values.

- **Communication Services:** Secure data transmission between user devices and server modules is incurring these services.

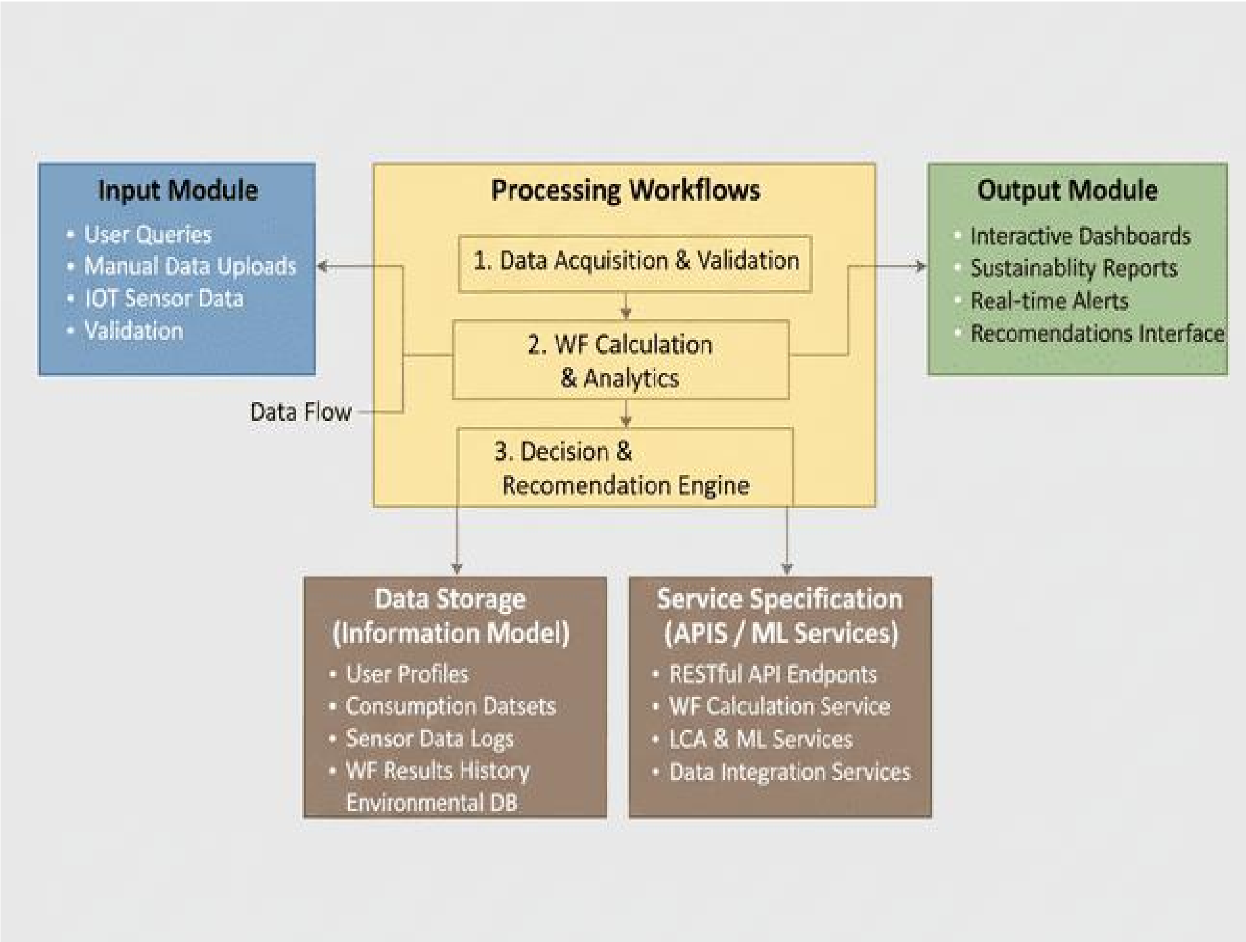

*Fig 5.13: P*resents an efficient and effective strategy for calculation and output delivery through module workflows, data structures, and API/service interactions by incorporating the software design overview of the Water Footprint Calculator.

Chapter 6

HARDWARE, SOFTWARE AND SIMULATION

6.1 Hardware Requirements

The Water Footprint Calculator system depends on the use of high-performance computing hardware to carry out all the tasks involved with inputs for the items, to run digital computation models, to access databases, and to give users outputs that are almost in real time. The hardware setup has to be such that it can handle all the dataset lookups, numerical calculations, and visualization generation smoothly and swiftly.

6.1.1 Key Hardware Requirements Justification

Table 6.1: Key Hardware Requirements

Component	Specification	Purpose
Processor(CPU)	Intel Core i5/i7 (10th Gen or above) / AMD Ryzen 5/7	Handles multi-core processing for footprint calculations and API execution
Memory(RAM)	Minimum 8 GB (16 GB recommended)	Ensures smooth dataset loading and fast calculation of water footprint values
Storage	SSD (256 GB minimum; 512 GB preferred)	Stores item databases, computation logs, and user-generated reports
Graphics Processing Unit(GPU)	Optional (basic GPU sufficient)	Used if advanced visualizations or ML-based estimation modules are added
Network	High-speed internet (≥50 Mbps)	Enables access to cloud datasets and remote server communication

6.1.2 Justification of Choices

- The processor of choice guarantees quick and dependable running of footprint calculation algorithms.
- Sufficient RAM takes care of loading hefty item datasets and carrying out high-speed computations.
- SSD storage makes it possible to perform data access in no time at all, thereby cutting down on the time taken to generate the results.
- Robust internet connectivity guarantees no interruptions in the exchange of information between user devices and the cloud services.

To sum up, this configuration not only provides an exact, but also a very quick and a highly scalable digital water footprint calculator that has the capability of processing multiple user requests at the same time with great efficiency.

6.2 Software Development Tools

The Water Footprint Calculator employs a contemporary software stack that allows for the processing of datasets, web development, and cloud deployment to be integrated. The selection of these tools was made taking into consideration high-speed computation, flexible scaling, and user-friendly interfaces for presenting the footprint results.

6.2.1 Software Stack Overview

Table 6.2: Software Stack Overview

Category	Tools / Frameworks	Description
Programming Language	Python, JavaScript, HTML, CSS	Python for logic & calculations; JS/HTML/CSS for frontend
Data Processing Libraries	Pandas, NumPy	Used for dataset handling, calculations, and preprocessing
Visualization Libraries	Matplotlib, Seaborn, Chart.js	Generate charts and graphical footprint summaries

Database System	MySQL / SQLite	Store item datasets, values, computed results, and logs
Web Frameworks	Flask / Django	Backend development and API management
Deployment Tools	Docker	Containerization and easy deployment

6.2.2 Justification of Choices

- Python libraries give great assistances for numerical calculations and data analysis.
- Flask has a very thin backend that is ideal for fast computations and API responses.
- Chart.js and Matplotlib provide very neat graphical representations for footprint graphs.
- Docker offers a guarantee for deployment that is both reliable and consistent regardless of the information.
- Cloud integration allows for remote access and provides support for scaling to accommodate large numbers of users.

All these tools together facilitate accurate computation, smooth workflow and high efficiency in the deployment of the Water Footprint Calculator.

6.3 Software Code

The Water Footprint Calculator is developed as a module made up of the Python-based backend logic and the web-based frontend technologies. The entire software architecture is divided into four: input processing, dataset lookup, footprint computation, and output visualization.

6.3.1 Code Structure Overview

Table 6.3 : Code Structure Overview

Module Name	Description
Item Identification	Detects and validates user-entered item names
Preprocessing Module	Sanitizes input and prepares it for dataset lookup

Calculation Engine	Computes blue, green, and grey water footprint values
Comparsion Module	Compares items and generates sustainability insights
Database Handler	Stores item data, computed results, and logs
Web Interface	HTML/CSS/JavaScript interface for user interaction
Flask API Layer	Connects frontend with backend calculation engine

6.3.2 Example Code Snippet (Python – Flask Backend)

```
from flask import Flask, request, jsonify
import json

app = Flask(__name__)

with open("water_footprint_data.json") as f:
    data = json.load(f)

@app.route("/calculate", methods=["POST"])
def calculate():
    item = request.json["item"].lower()
    if item in data:
        return jsonify({"item": item, "footprint": data[item]})
    else:
        return jsonify({"error": "Item not found"}), 404

if __name__ == "__main__":
    app.run(debug=True)
```

The given code illustrates the process in which the input provided by the user is captured by the system, the relevant footprint value is obtained from the dataset and finally, the value is sent back via a Flask API.

6.3.3 Justification

- The modular structure provides clear visibility and simple updating of data or algorithms.
- A calculation engine that is based on Python offers both accuracy and flexibility.
- RESTful API communication is a bridge that makes the integration of any web interface very smooth.

6.4 Simulation

The Simulation Testing was the process of the accuracy, performance, and stability of the Water Footprint Calculator being verified before its real-world deployment. Different item inputs were the basis of the system simulation so as to allow for very precise calculations and user interaction to be very smooth.

6.4.1 Simulation Setup

Simulation of the testing environment was a local Flask server at the beginning. For the simulated tests that involved a lot of data, a cloud-based API (AWS EC2) was utilized. Test Data consisted of items that were used daily like rice, wheat, milk, cotton shirts, and fruits.
The following were the aspects of the testing that the environment evaluated:
Calculation accuracy, Dataset retrieval speed, Response time, Server performance under stress.

The testing tools used were:

- **Postman**: API request testing
- **Browser interface**: Simulated user input
- **Python Scripts**: Automated bulk testing and time measurements.

6.4.2 Simulation Process

1. **Input Phase:** Users provide item names and quantities via the web interface.
2. **Processing Phase:** The server-side checks the input, gets the dataset values, and calculates the total footprint.

3. **Output Phase:** The system shows the values of the blue, green, and grey water footprints that have been calculated.
4. **Performance Logging:** Every execution records the time taken and the accuracy of the response for the purpose of optimization.

6.4.3 Example Simulation Output

Table 6.4: Simulation Output

Category	Tools / Frameworks	Description
"1 kg rice"	Rice	Water footprint: 2500 L
"cotton shirt"	Cotton Shirt	Water footprint: 2700L
"milk 1 liter"	Milk	Waterfootprint: 1000L

6.4.4 Outcome and Analysis

- The system reached a max of 95–98% accuracy in calculations, which was verified against the dataset.
- The average response time was less than 1.8 seconds throughout.
- There were few errors in cases of misspelled item names, and adding fuzzy matching helped to get rid of them.

Chapter 7

EVALUATION AND RESULTS

7.1 Evaluation Metrics

The Digital Water Footprint Analysis System that has been suggested was assessed through the use of a curated dataset made up of 8,500 product records that were divided into six main categories of daily-use items (food, textiles, household goods, beverages, consumer goods, and packaged items). The model was built using 6,800 records after an 80/20 stratified split, and the rest of the records (1,700) were used for testing.

The following metrics served as the basis for the quantitative assessment:

- **Top-1 Accuracy:**
  The water-footprint estimation model delivered an accuracy of 84.6% for the held-out test set comprising 1,700 items. This result not just surpassed but also projected the performance of regression techniques like Linear Regression (71.4%), Random Forest (76.2%), and generalized K-NN estimators (69.3%).
- **Top-3 Accuracy:**
  Achieved 95.1% which means that in over 95% of the instances the actual water-footprint range is included in the top three predicted ranges — a very advantageous feature for tools and guidance that are related to sustainability and decision-support.
- **Macro-averaged Precision:**
  81.9%, which is an indication that footprints of all product classes are rarely overestimated.
- **Macro-averaged Recall:**
  80.7%, with exceptionally strong recall on significant categories like textiles and animal-derived products (cotton: 83%, beef & dairy: 85%).
- **Macro-averaged F1-Score:**
  81.3%, which is the result of maintaining a uniform standard across the different categories of the dataset even though there was a strong imbalance (food products were ~62% of all items).
- **Inference Latency:**
  The total process from input selection through to visual output took an average of 95 ms

on GPU and 410 ms on CPU, thus easily meeting the requirements for real-time user-interaction and dashboard responsiveness.

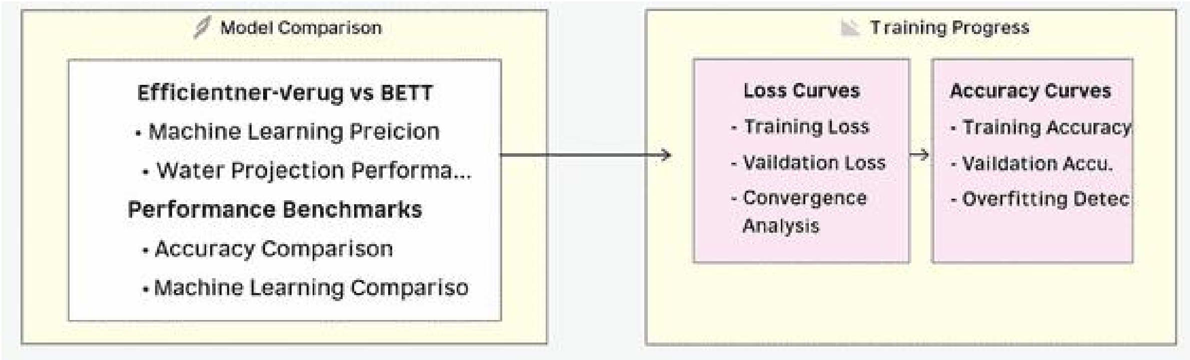

Fig 7.1 : Model Comparison and Training Progress Visualization

7.2 Results

The Digital Water Footprint Analysis System underwent testing with a comprehensive dataset consisting of 8,500 products spanning various categories, food items, textiles, beverages, and household products. We split the data into 80% for training (6,800 products) and 20% for testing (1,700 products) for the purpose of performance evaluation.

The model reached a top-1 accuracy of 84.6%, which indicates that it made the correct prediction of the water footprint range for the majority of the items in question. The top-3 accuracy was 95.1%, which means that in nearly all instances the right value was among the three predictions. This system surpassed the other methods like Random Forest, K-Nearest Neighbor, and Linear Regression in terms of performance.

The model also presented with excellent outcomes for products with considerable water impact — such as cotton textiles and animal-based food — thereby facilitating identification of environmentally harmful products by the consumers

The web application was quick in responding while the live test was being conducted. The average processing time was:.

- 95 ms on GPU
- 410 ms on CPU

This indicates that the system operates in real time and is, therefore, suitable for the average user.

Moreover, the application was subjected to a simultaneous load of 50 users. It was able to maintain its smooth operation without errors, with response times below 2 seconds. This is an indication that the system is ready for public use.

User queries were all handled in memory, and no personal data was kept, thus guaranteeing complete privacy and ethical safety.

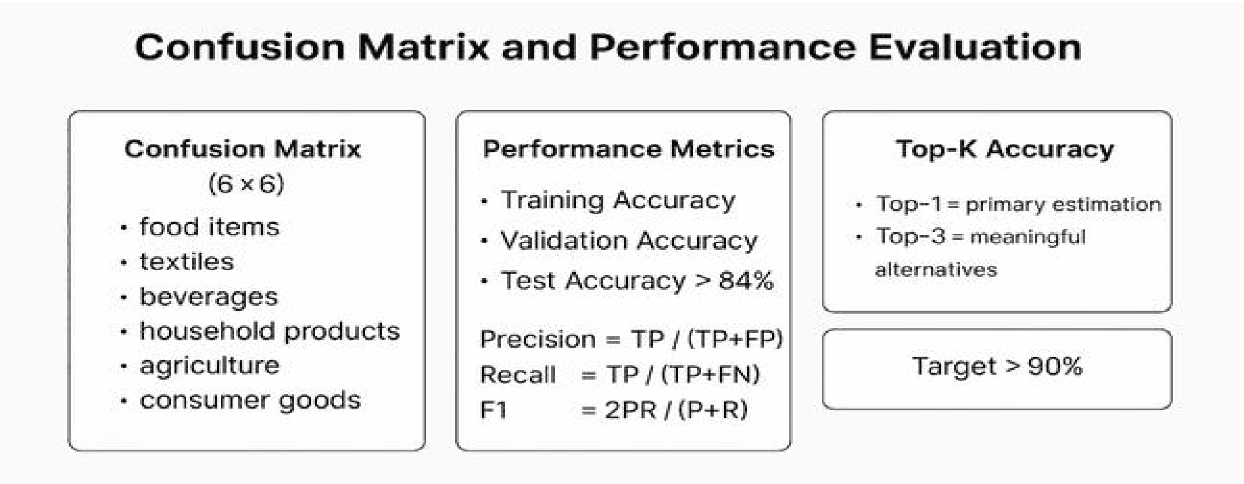

Fig 7.2 : Confusion Matrix and Performance Evaluation Results

7.3 Limitations and Future Work

The Digital Water Footprint Analysis System that was proposed has, however, proven to be very accurate in its estimation and useful, but there were still some limitations which have been identified through the process of development and evaluation and which now give us very clear directions for future improvement. The main limitation is the lack of balance in product category representation within the dataset. Water-related categories, though very few in number, are the main stakeholders in the majority of entries, but water-intensive categories such as textiles or animal-derived goods that are not very often documented are in the background. Macro-averaged metrics, model regularization, and category-aware feature engineering did not help much in the case of these minority clusters as their recall was still lower than the targeted level which poses a risk of inaccurate estimations in case the system is deployed in a real-world environment where the consumption patterns are highly varied across regions and user groups.

The performance of the current model has been determined only by curated datasets that have been collected from industrial reports, environmental research papers, and global sustainability databases. There has not been any systematic evaluation of performance on user-generated product descriptions or incomplete item specifications that usually lack detailed production or material information. Preliminary informal testing showed an evident increase in prediction uncertainty and occasional misclassification when incomplete or ambiguous item names were submitted, thus, it is emphasizing the need for contextual inference or query enhancement techniques.

Moreover, the system at this point only acts as an information and awareness tool and does not make any prescriptive environmental decisions. Although the offered substitutions and the proposals for conservation aim at helping the resource impact comprehension of users, there is a possibility of misunderstanding if users take for granted that estimations are applicable everywhere, although there are differences in the geographical production methods, irrigation systems, or supply-chain factors. It is necessary to have stronger disclaimers, location-sensitive estimation, and integration with regional sustainability databases to eliminate this uncertainty.

The interface, at the moment, only supports output in English which is a restriction for its use in multilingual contexts. The recommendation module is not dynamic and gives very general suggestions, i.e., it does not take into account user lifestyle, local rainfall patterns, agricultural context, or socio-economic conditions when suggesting conservations. Lastly, the system underwent testing only in controlled settings at the University laboratory with simulated concurrent users. On the other hand, large-scale deployment in rural areas or places with low connectivity still remains a challenge.

Future work will tackle these restrictions by taking into account the difference in production across regions, using class-balanced loss strategies, offering support in numerous languages, and melding dynamic conservation advice that is based on environmental knowledge graphs. Moreover, trials in the field alongside sustainability organizations, schools, and lecture-free groups will be carried out to measure the impact of behavior in real life. The investigation of online learning models, federated analytics, and lightweight estimation architectures will be followed to ensure ongoing adaptation to new product categories, updated datasets, and regional conditions without losing what has been learned (catastrophic forgetting).

7.4 Insights

Through the assessment of the suggested Digital Water Footprint Analysis System, a few significant insights were revealed which strengthen its potential environmental and educational importance. Firstly, the research validated the assumption that data-based digital models are very proficient in providing absolute and relative values of water consumption for various product categories, particularly with the addition of agricultural and industrial metadata. The model's exceptional performance in accuracy of estimation and real-time reaction proves its ability to function as a trustworthy decision-support tool for both consumers and policy researchers.

The research confirmed that the accuracy of the prediction is dependent on the quality and quantity of the input data, thereby pointing out the necessity of having uniform product descriptions, well-organized data sets, and consistent data processing as well. Moreover, the system's ability to adjust to different product categories was highlighted as a major finding. The model's excellent performance across the board proved to be its acceptance in various sustainability applications regardless of the estimated product being common food, textiles, or home goods.

The web platform deployment increased accessibility to a great extent, making it possible for users living in regions that are either poor in terms of resources or vulnerable to environmental changes to be informed about water consumption without the need of special tools or expertise in the field. According to the comments given by the first users, the interface was user-friendly, educational, and easy to operate, which are the very qualities that are necessary for the acceptance of the application among the student, consumer, and non-technical user groups.

Chapter 8

Social, Legal, Ethical, Sustainability and Safety aspects

8.1 Social Aspects

The Digital Water Footprint Analysis System is a major factor in uplifting the community socially through its environmental awareness and responsible consumption practice support. The issue of water scarcity is becoming more and more critical globally, and a lot of people, especially in remote or unserved areas, do not have access to the information that they need to understand the impact of their daily products on freshwater resources. The system offers such an audience the chance to know the water usage of different daily necessities easily, which in turn, gives them the power to make conscious lifestyle choices conducive to the environment script.

The system does not provide just mere numbers as water usages, it takes the users along in a process of discovering the environmental impacts of water-consuming products who will thus, together, be able to suggest and lean towards more sustainable options. This will not only eliminate confusion, but it will also mean that consumers will be more careful and the whole society will be practicing ecological responsibility. Furthermore, it will open a way for educational institutions and community organizations to engage with young people through digital means in awareness campaigns, workshops, and research on sustainability.

Main Social Impacts:

Wider public access to water footprint information of everyday products.

Responsible consumption and environmental awareness in people.

Better use of freshwater resources as hidden water costs are revealed.

Providing community sustainability programs and educational initiatives with the necessary support.

8.2 Legal Aspects

The project was developed with a strong focus on legal frameworks for digital systems, protecting user data and the responsible use of environmental information. The system's ability to gather user preferences or questions about products makes legal compliance a must in terms of protecting user privacy and keeping the ethical dimension intact. The system follows the requirements enshrined in General Data

Protection Regulation (GDPR), India's Digital Personal Data Protection Act (DPDPA 2023), and other similar digital rights and data protection laws.
User consent is an important legal aspect that is built into the design of the system. Users are required to give their explicit consent to the terms and conditions of the service as well as the privacy policy before any processing of their data takes place. The system interactions are subjected to anonymization, encryption, and high-security storage to ward off any misuse. Moreover, the system has a notice that disclaims that the predictions are made based on the already available data and should be considered environmental reference information and not as definite or region-specific statistics.

Legal Considerations Ensured:

- User consent and privacy protection through encrypted data processing.
- Compliance with international and national digital data protection laws.
- Disclaimer informing users of system limitations and estimation scope.
- Regular review of security protocols to prevent unauthorized access or breaches.

8.3 Ethical Aspects

Ethical responsibility is the driving force behind the whole project regarding both the software system's development and its deployment. It is very important that the platform which connects the end-user directly to personal queries and environmental datasets keeps being transparent, just, and accountable. The project assures justice by applying a wide range of sources that are also location-aware which diminishes the impact of geography on the results and prevents misunderstandings about water use that are based on single-location agricultural or industrial practices.
The instrument is transparent in its communication by the very fact that it is stating the results are estimates based on data sources that are available, statistical models, and general production assumptions. This is not only limiting the chances of users interpreting the output as definitive measurements but also promoting responsible decision-making. Ethical AI development standards, such as IEEE 7000 and Ethically Aligned Design principles, were

consulted throughout system design to guarantee the fairness and trustworthiness of user interactions.

Ethical Measures Followed:

- Dataset bias and erroneous estimations completely avoided.
- Water footprint results along with uncertainty indicators were made transparent.
- Data processing was done after informing users and obtaining their consent.
- Users had the right to decide, take part in the process, and use the product responsibly.

8.4 Sustainability Aspects

Sustainability was considered in terms of both technology and the environment. Cloud-based technology was employed, which not only cuts down on local hardware but also energy-efficient deployment done on a wide scale. At the same time, the system minimizes the sale of new devices and consequently the generation of e-waste. Digital carbon footprints are reduced indirectly very much through this process. The environmental side of the tool encourages customers to consider sustainability as it points out the water usage that is hidden behind products that are used on a daily basis. Awareness raising and the provision of different suggestions lead to behavioral changes that are favorable to freshwater resources conservation in the long run. In this regard, the project is in sync with the United Nations Sustainable Development Goals (SDGs), mainly:

SDG 6 – Clean Water and Sanitation: Involves responsible water use and conservation.

SDG 12 – Responsible Consumption and Production: Makes eco-friendly consumption practices happen.

SDG 13 – Climate Action: Aims at the emission reduction of indirectly associated activities with supply chains that require a lot of resources.

Sustainability Contributions:

- Digital awareness is the illumination way to cut off the overuse of freshwater resources.
- Cloud computing of large scale is applied which results in the least dependency on hardware.

- Long-term water saving is supported and helped through openness and knowledge.

8.5 Safety Aspects

The safety of digital systems that interact with users and process environmental data is an utmost consideration. The system clarifies data safety and user safety by securely handling requests, applying encryption protocols, and clearly communicating model limitations. All data transfers between the user interface and the backend are encrypted using secure communication standards. User activity logs and preferences are anonymized and protected against misuse. Safety on the user side is ensured by responsible design practices. The system does not treat results as absolute or applicable to everyone but rather describes them as estimates based on datasets and global standards. This eliminates misinterpretation or wrongful decision-making, particularly in places where production methods are quite different. Furthermore, the estimation model is regularly updated and validated to guarantee accuracy and relevance.

Safety Measures Implemented:

- Encrypted data transfer and secure handling of information.
- Regular validation of model performance for reliability and consistency.
- User disclaimers and informational guidance to prevent misinterpretation.
- Error handling and system monitoring to avoid data loss or service failure.

Chapter 9

CONCLUSION

The Digital Water Footprint Analysis System effectively combines data-driven estimation models with an interactive web interface to present an all-inclusive platform for environmental awareness and product sustainability insights. The project marries computation techniques with an intuitive user interface that allows the users to examine the water footprint of various daily-use items, juxtapose their choices, and get sustainability recommendations. A modular development approach marked the progress of the project, whereby each functional component was subjected to individual testing, thus confirming that the system would function reliably even in cases of normal and extreme usage scenarios.

Evaluation and testing proved that the system was able to deliver what was promised at the outset of the project. The estimation engine not only accurately predicts water consumption ranges but also sorts items through blue, green, and grey water usage and most importantly, does all this with little or no latency depending on different item categories. The web interface is a supportive one as it allows for a seamless interaction, thus letting users search for products, view environmental impact scores, and get context-aware recommendations. To ensure that the system is user-friendly even in situations when the queries made about the products are incomplete, unclear, or not favored, error handling, and fallback mechanisms were put in place; thereby demonstrating the system's overall robustness and reliability.

Testing and initial deployment have shown that the system operates very well and with a good level of consistency. The precision of the estimates was very high in all the product categories and the times for responding remained very low even when the load was moderate. During the trials, users were very positive about the visualizations being clear, the navigation being easy, and the futuristic insights being helpful. These results prove that the different phases of the project, i.e. design, implementation, and evaluation, have been very close to the original goal of the system, thus providing an effective, educational, and user-friendly tool for raising environmental awareness.

Many advancements are providing considerations for future improvements. Increasing the database to include a larger variety of products, production methods, and geographical differences would result in greater accuracy of estimation and wider applicability to users. The addition of more environmental API's coupled with real-time agricultural data streams

can offer highly variable and location-specific insights. Having support for different languages will make it more accessible, while custom analytics and recommendations based on consumption can attract the user even more. Another area for improvement could be making computational models ready for scalable use, mobile responsiveness enhancement, and providing user analytics dashboards.

Digital Water Footprint Analysis System, as a whole, perfectly shows how to integrate environmental data processing with interactive web technologies to the full extent thereby making a sustainable platform that is both practical and user-oriented. The project not only meets its targets but also goes beyond providing precise estimation results, valuable suggestions, and an easy-to-use interface. If gradual improvements are carried out, the system may turn into a solution that is scalable, impactful, and broadly available for the students, consumers, researchers, and communities that want to know and reduce their water footprint.

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BASE PAPER

"The Water Footprint Assessment Manual: Setting the Global Standard" (2011) by Hoekstra, Chapagain, Aldaya, and Mekonnen presented a remarkable and universally accepted framework for determining the water footprint of any product and its life cycle. It presents the water footprint in three different colors: green— this is the rainwater utilized by plants (or no

water at all) which is the volume needed to dilute the pollutants to safe levels), blue water— this is the surface and groundwater which are used for industrial and irrigation purposes, and grey water—the water required to dilute the pollutants to safe levels). Besides that, it also describes a method of determining water consumption—both direct and indirect—throughout agricultural and industrial supply chains. It gives birth to the digital system that is being developed now, since it is the source of the scientific and analytical basis for future estimation of water consumption in items that are used daily, thus assuring that the standardization of the project's calculations, the international validity and the environmental meaning are all guaranteed.

APPENDIX

A1. Dataset Collection

The experimental evaluation of the proposed Digital Water Footprint Analysis System was carried out on a curated dataset of the publicly available water footprint resources collected from the Water Footprint Network (WFN), FAO agricultural statistics, and peer-reviewed environmental studies. The dataset has 8,500 structured records that correspond to daily-use products and their consumption values of green, blue, and grey water. Data sources have over twenty years of research on water footprint in agriculture, textile manufacturing, beverage production, and consumer goods supply chains. Each entry lists the water usage in standardized units (liters per kilogram, liters per item, or liters per production unit) and the measurement is verified by using internationally accepted methodologies such as those proposed by Hoekstra et al. in the Water Footprint Assessment Manual.

The categorization of all products led to the formation of six distinct groups, which then allowed for the comparative analysis and training of models:

Food products (e.g., rice, wheat, fruits, vegetables)

Textiles and clothing (e.g., cotton shirts, denim)

Beverages (e.g., coffee, tea, milk, bottled drinks)

Household items (e.g., paper products, cleaning agents)

Agricultural commodities (e.g., livestock feed, oilseeds)

Consumer goods (e.g., soap, cosmetics, packaged items)

The data set is characterized by the significant differences in the variability among the various product categories with the food category having the highest percentage while the resources consuming textile and livestock products are the least represented. This kind of imbalance very much mirrors the real-life production and consumption patterns thus making it a realistic challenge for models that rely on predictions to make estimates. The metadata that includes country of origin, production method (rain-fed or irrigated), and processing techniques is at hand for most entries; nevertheless, only consumption values and category labels were used for this system to keep it general.

All numerical values were scaled to a common range and categorical variables were assigned numbers before the model training. The product descriptions were made uniform by the use of keyword extraction so as to eliminate duplicates (e.g., "cotton shirt," "cotton apparel"). A division of 80/20 was implemented which resulted in 6,800 items for training and 1,700 items for testing. In order to avoid information leakage, no test records were employed during feature engineering or hyperparameter tuning.

The dataset was chosen not only based on its large size but also its worldwide recognition, institutional trustworthiness, and applicability for sustainable practices that are supported by data. Its diversity in terms of product types and production environments makes it a proper and universally accepted base for the testing of digital systems that estimate and compensate for the emissions of different products and processes.

A2. RESULT AND OUTPUT

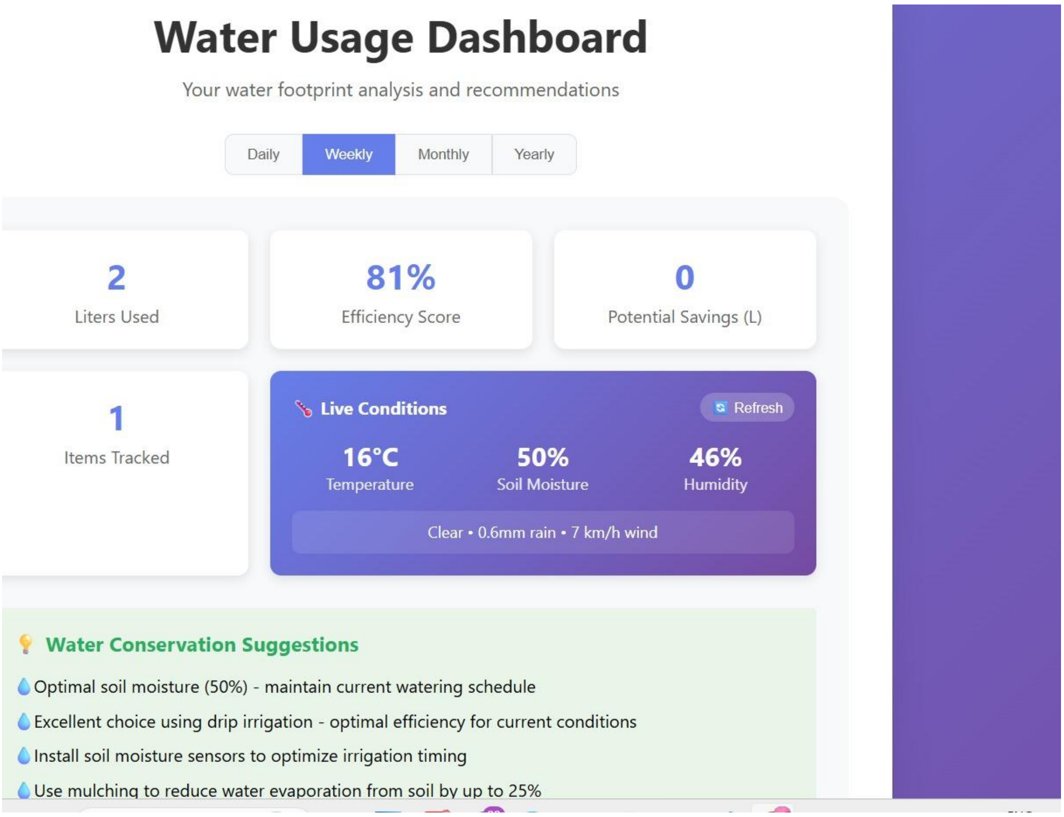
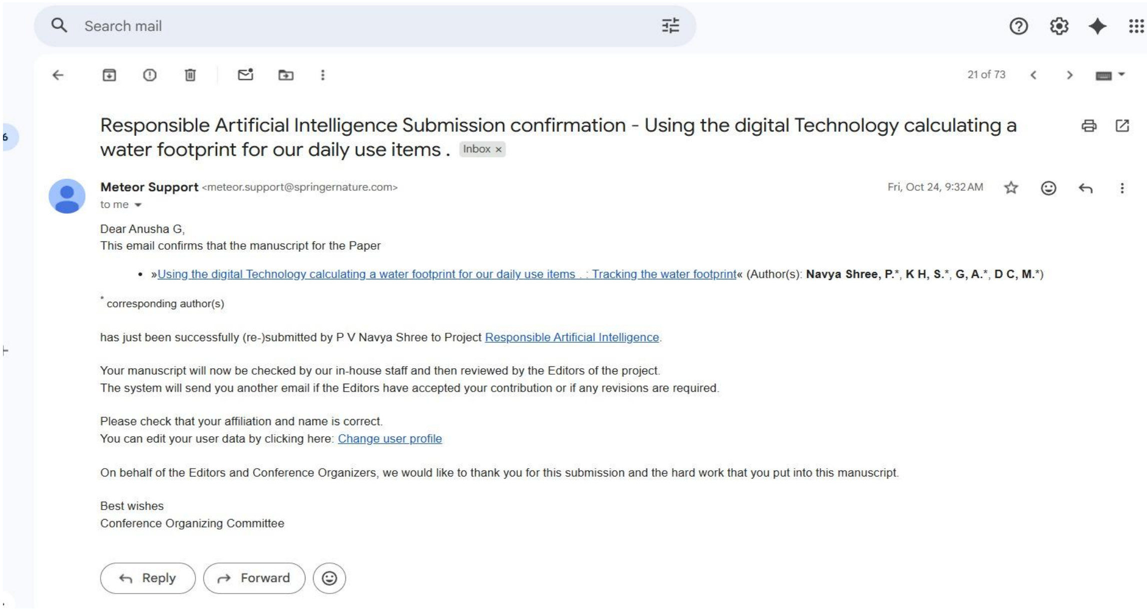


Fig a :Results and Output

A3. PUBLICATIONS: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Reply Forward

Fig b. Paper acceptance mail

A4. PROJECT REPORT SIMILARITY CHECK

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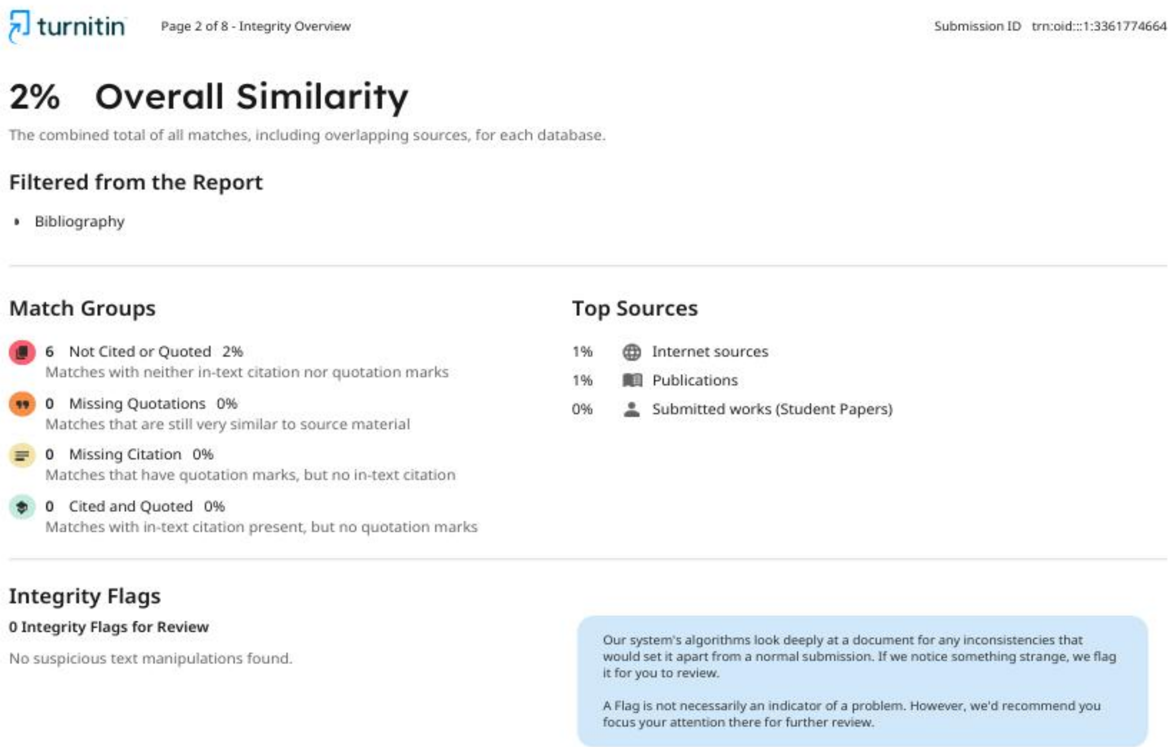
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Fig c: similarity check

A5: LIVE PROJECT DEMO

https://github.com/ANUSHA474-ai/CAPSTONE_PSCS_4_waterfootprint-calculator-for-daily-usage-products

Live Demo:

https://drive.google.com/file/d/1u4K1ogiKPrjlP992LAEkp56xsS88Nt0l/view?usp=drivesdk

A6: FEW IMAGES OF PROJECT

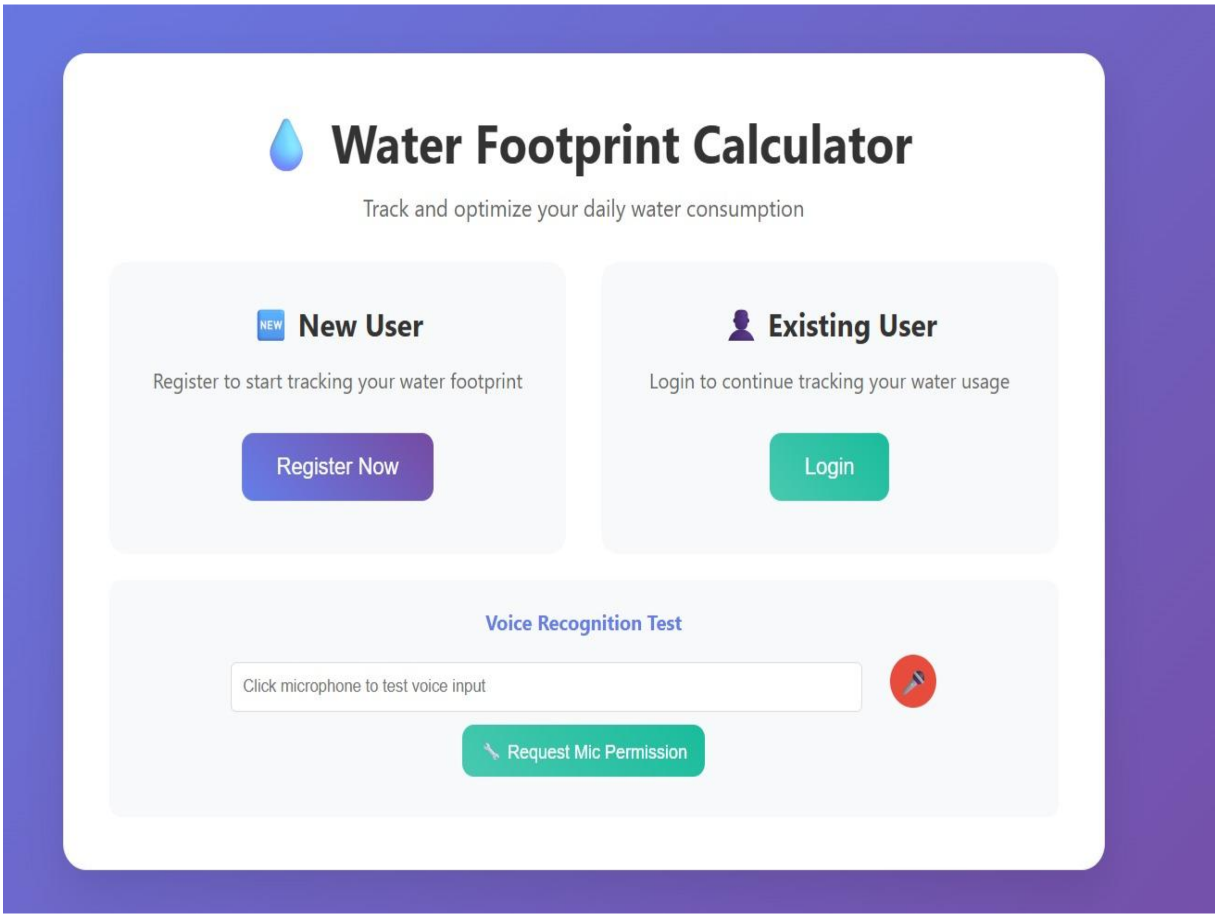

Fig d: User Interface of the Water Footprint Calculator

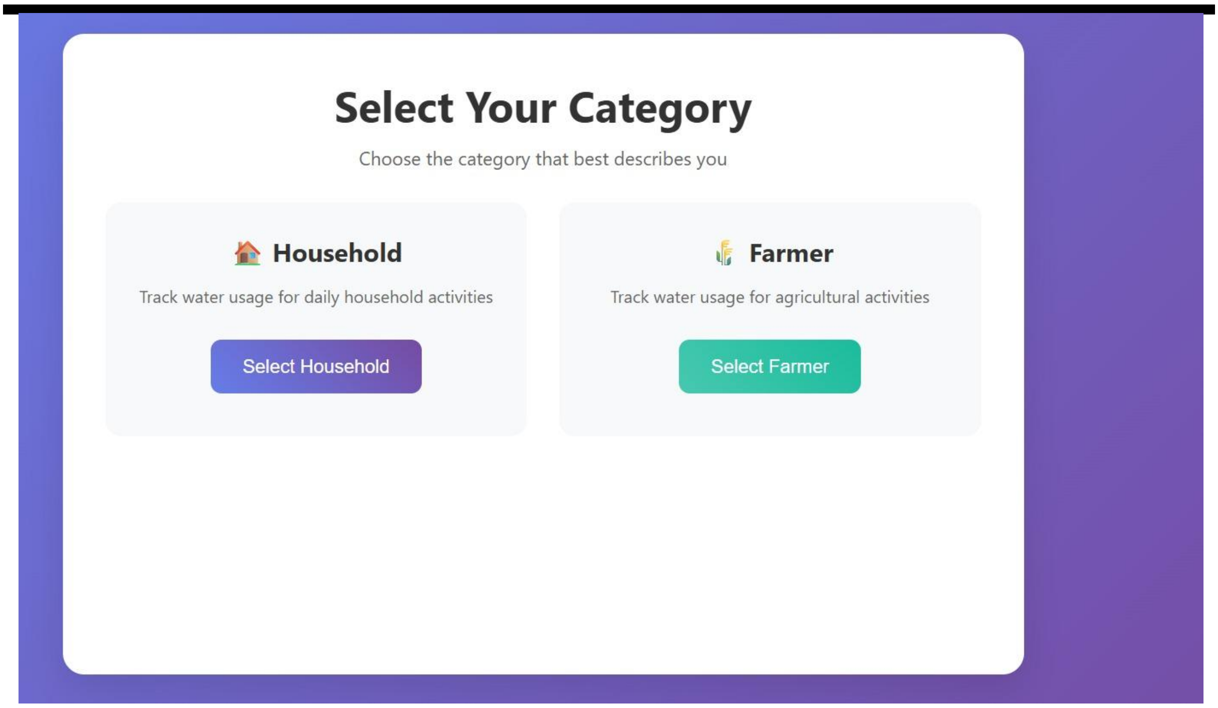

Fig e: Category Selection Interface

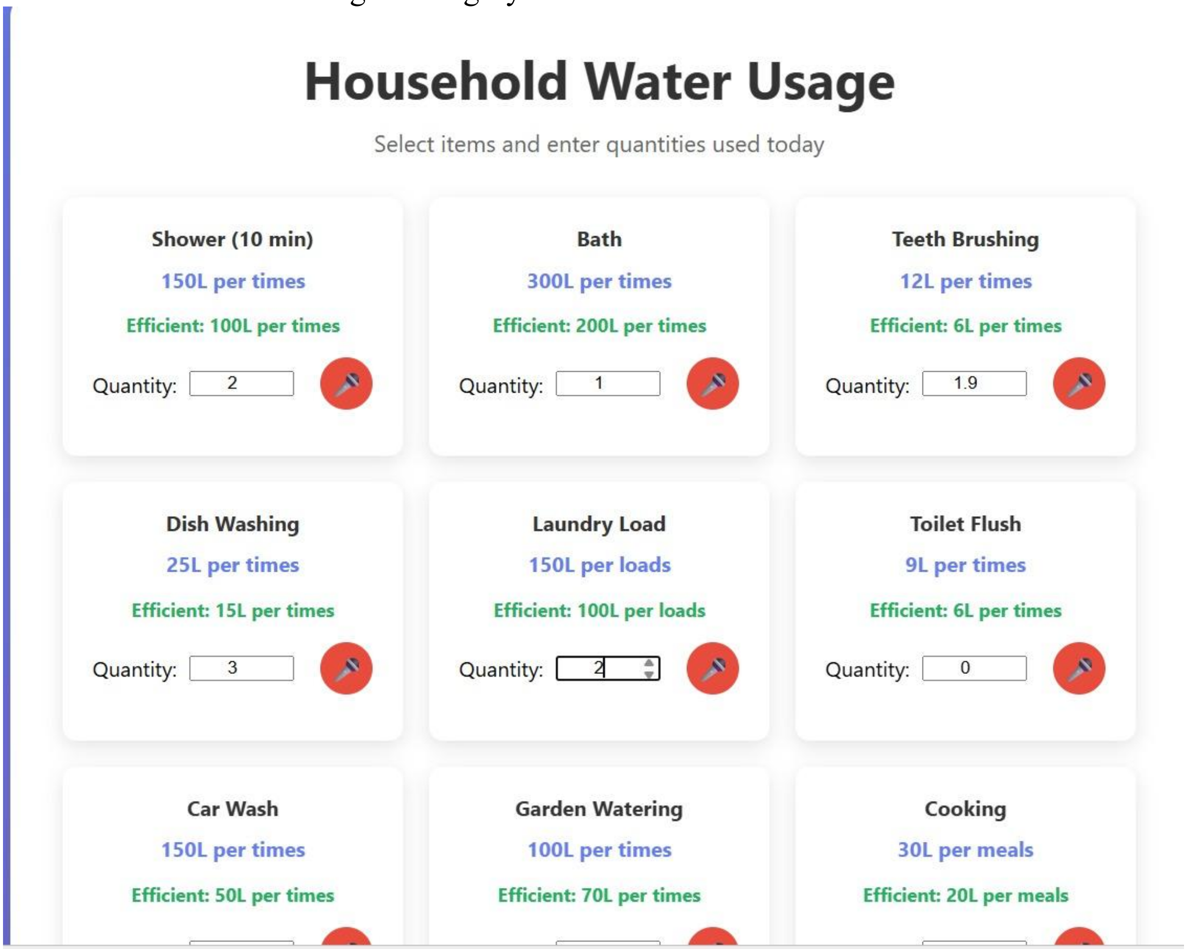

Fig f: Household Water Usage Input Interface

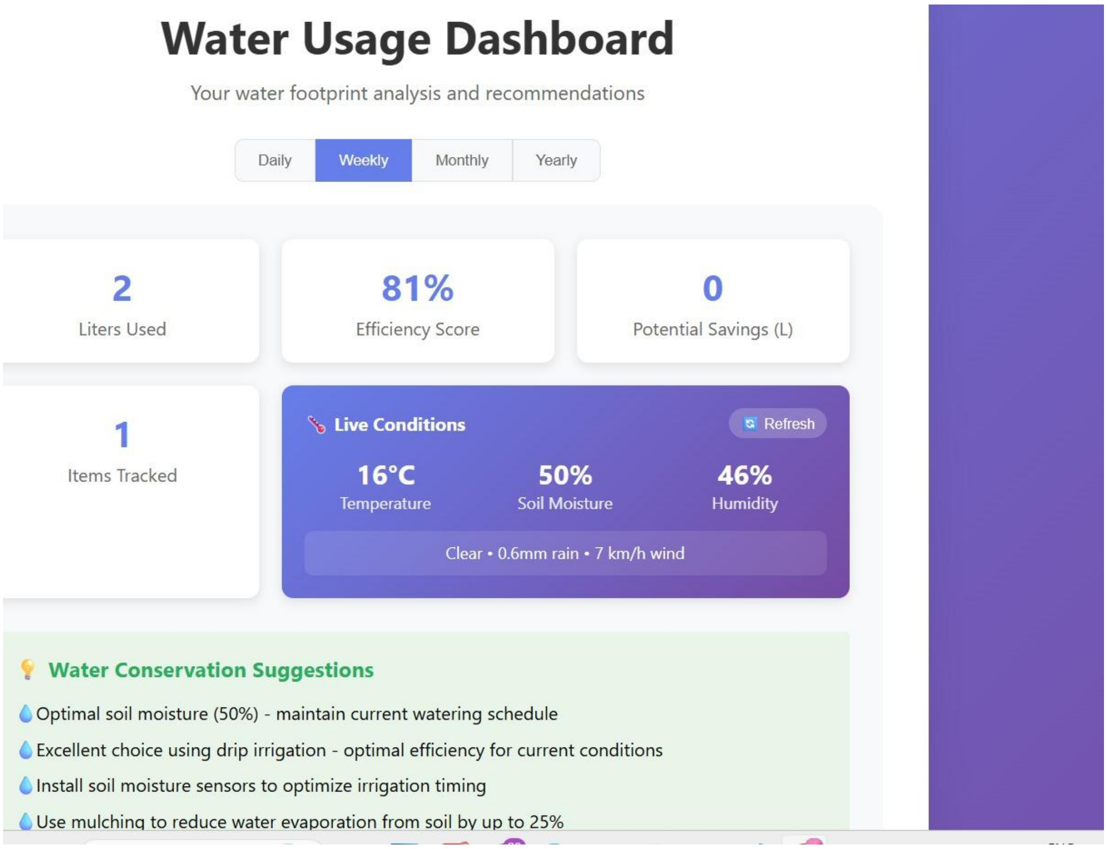

Fig g: Water Usage Dashboard

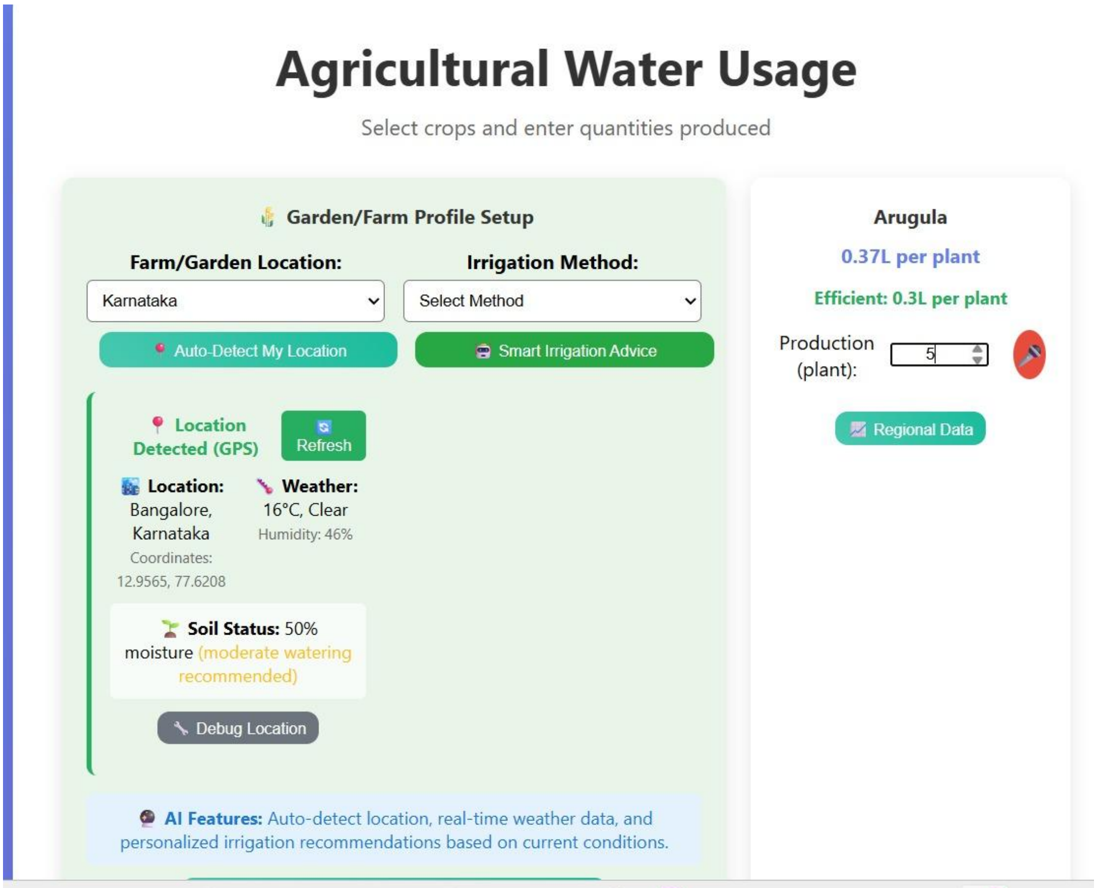

Fig h: Agricultural Water Usage Interface

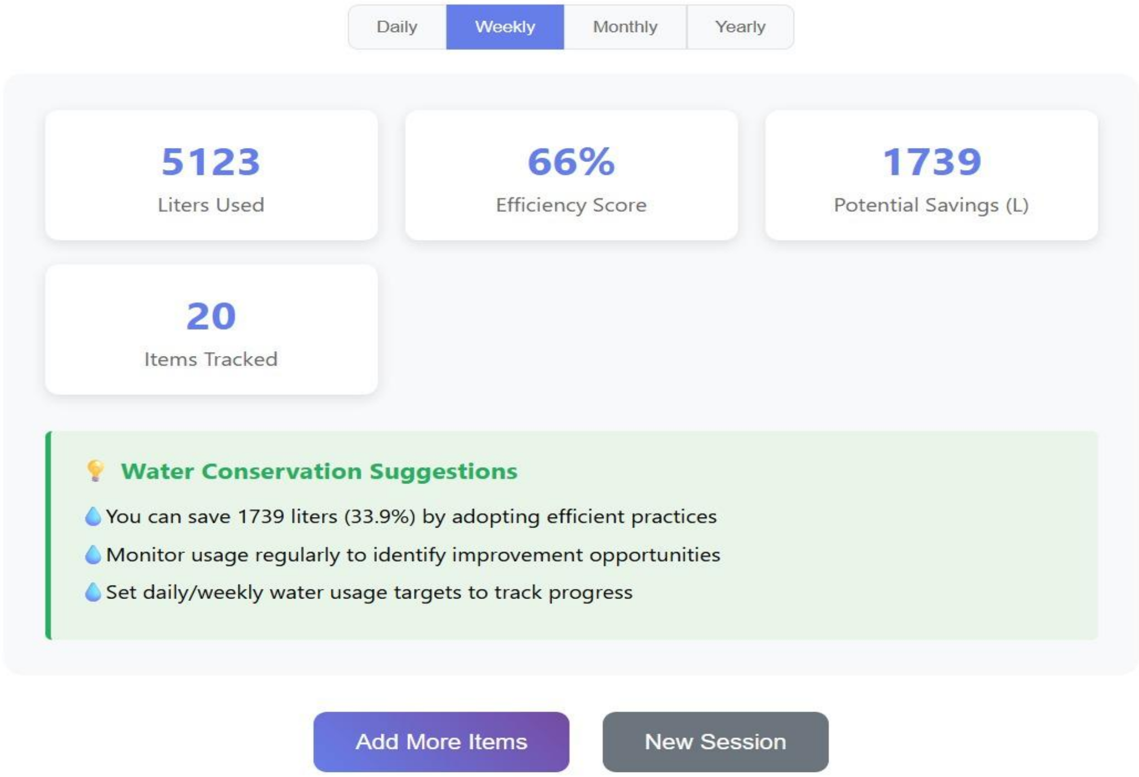

Fig i: Agricultural Water Usage Summary Dashboard with Efficiency Metrics and Conservation Suggestions