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ICT-based management of shower water use in Niamey hotels: research and development of a smart water-saving device (WSD) system.

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DEDICATION

I dedicate this Master Thesis to my dear parents who without their support and advice, I would not be at this level today.

This work is also dedicated to my little sisters Leyhana, Zoulhatou and Zouera for their love and support.

Finally, a special dedication to my dear uncle Mr. Garba MOUSSA KIMBA aka GMK for his constant support and encouragement since my primary studies until today.

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ABSTRACT

Many cities in the world are expected to face freshwater shortages in the future due to population growth combined with urbanization and the related decline in renewable freshwater resources caused by the effects of climate change. Niamey, the capital of Niger is no exception. In addition to these three (3) phenomena which threaten water resources, there is also a waste of water, especially in urban areas. Thus, hotels are places in cities where a lot of water is wasted by guests. In this work, the average daily amount of shower water per customer in Niamey hotels was estimated and a smart water-saving device (WSD) system was developed for ICT-based and mitigation-driven shower water management in Niamey hotels. Water-saving devices are well-known examples of Environmentally Sound Technologies (ESTs) used for water conservation and water waste reduction. However, after collecting data from some representative hotels in Niamey, the average daily amount of shower water per guest was estimated at 92.07L. Then, by making some assumptions, it is shown that the smart water-saving device system can reduce the consumed shower water of Niamey hotels by up to about 45.70%.

Keywords: water-saving device (WSD); Niamey hotels; Environmentally Sound Technologies (ESTs); water conservation.

RESUME

De nombreuses villes dans le monde devraient être confrontées à des pénuries d'eau douce à l'avenir en raison de la croissance démographique combinée à l'urbanisation et de la diminution connexe des ressources renouvelables en eau douce causée par les effets du changement climatique. Niamey, la capitale du Niger, ne fait pas exception. En plus de ces trois (3) phénomènes qui menacent les ressources en eau, il y a aussi le gaspillage de l'eau, surtout en milieu urbain. Ainsi, les hôtels sont des lieux dans les villes où beaucoup d'eau est gaspillée par les clients. Dans ce travail, la quantité quotidienne moyenne d'eau de douche par client dans les hôtels de Niamey a été estimée et un système de dispositif intelligent d'économie d'eau (WSD) a été développé pour une gestion de l'eau de douche basée sur les TIC et axée sur l'atténuation dans les hôtels de Niamey. Les dispositifs d'économie d'eau sont des exemples bien connus de technologies respectueuses de l'environnement (TSE) utilisées pour la conservation de l'eau et la réduction des déchets d'eau. Cependant, après avoir collecté des données auprès de certains hôtels représentatifs de Niamey, la quantité quotidienne moyenne d'eau de douche par client a été estimée à 92,07 litres. Ensuite, en faisant quelques hypothèses, il est démontré que le système de dispositifs intelligents d'économie d'eau peut réduire la consommation d'eau de douche des hôtels de Niamey d'environ 45,70%.

Mots-clés: dispositif d'économie d'eau ; hôtels de Niamey ; technologies respectueuses de l'environnement ; conservation d’eau.

ACRONYMS AND ABREVIATIONS

ANGPDH: Average Number of Guest Per Day in a Hotel

API: Application Programming Interface

DAASWH: Daily Average Amount of Showering Water of a Hotel

DRTA: Direction Régionale du Tourisme et de l'Artisanat

ESTs: Environmentally Sound Technologies

GPS: Global Positioning System

IDE: Integrated Development Environment

IETC: International Environmental Technology Centre

IoT: Internet of Things

LCD: Liquid Crystal Display

LED: Light Emitting Diode

ML/D: Mega Liters per Day

NGBH: Number of Guest Beds in a Hotel

ORH: Occupancy Rate of the Hotel.

RTC: Real Time Clock

TWCPMH: Total Water Consumption Per Month of a Hotel

UN: United Nations

UNEP: United Nations on Environmental Protection

WDS: Water-Saving Device

WTO: World Trade Organization (WTO)

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INTRODUCTION

I Context

Climate change is a real and global problem. Several authors have highlighted the growing pressure on water resources as one of the consequences of climate change ((Krinner et al., 2013); (Ozor, 2015) ;(Impacts & Rivers, 2017) ; Rousset, 2020)). Indeed, it is shown that a change and variability in climate have and will continue to have a profound impact on the water sector through the hydrologic cycle, water availability, water demand, and water allocation at the global level, but also at African regional, basin, and local levels (*Linking Climate Change and Water Resources: Impacts and Responses*, 2016). Urbanization is also one of the most significant trends of the 21st century, affecting in general the global economic development and particular water resources (McDonald et al., 2014). "Urbanization is defined as the increase in the proportion of people living in towns and cities. It can also be defined as the process whereby a society changes from a rural to an urban way of life. " (MeSH, 2017 ; Simwela et al., 2018). By 2050 it is predicted that 67% of the world population is expected to be living in urban areas, with the most rapid levels of urbanization taking place in developing countries especially those in West Africa (Cullis et al., 2019). In addition, the continuously growing population in combination with the escalating urbanization and economic growth increase the demand for water (Stamou & Rutschmann, 2018). However, the negative impacts of climate change and urbanization combined with population pose serious challenges on water resources in developing countries especially those in West Africa where resources to mitigate these impacts are limited.

In Niamey, the capital of Niger, due to recurrent climate change impacts such as floods and droughts, the Niger River which is the primary surface water used for agriculture and for the drinking water supply cannot fulfill the total water demand for the area (Boko et al., 2020). In addition, the population growth rate of Niamey is staggering. From a small village of 4,000 habitants in 1930, Niamey's population is projected to be 2,1 million by 2025 (*Market in Niamey, Niger Source: Http://En.Loadtr.Com/21_Niamey_Niger- 423880.Htm*, n.d.). Then, with such a population growth rate, the increase of water demand in Niamey city is obvious. Boko et al. (2020) also stated that the demand on groundwater supply to meet drinking and agricultural water use needs in Niamey is increasing, due to rapid population growth and urbanization. Despite these three (3) phenomena (climate change, urbanization and population growth), a large amount of water is wasted in hotels by users/guests every day (Willis et al., 2010). According to Keough & Saidou (2021), poor people in Niamey (more than 40% of Niamey's population) are suffering because they use more time to get drinking water from standpipes or from street vendors "ga'ruwa" in Hausa (literally "there is water"). Poor people in Niamey also pay on average five times more the price of water than non-poor and this is seen as a social inequality.

Given the water wasted by non-poor people in Niamey while the poor ones are suffering to get drinking water, walking many kilometers and paying five (5) times more than non-poor, adopting good measures of water management especially in hotel showers could significantly reduce water waste in that city. "Since the 1970s, it has been demonstrated that good water management is possible, financially feasible, and practicable within urban low-income areas when considering the use and applications as well as the approaches of appropriate technologies that are known today as Environmentally Sound Technologies (ESTs) " (Schuetze & Santiago-fandiño, 2013).

Water-Saving Devices (WSDs) are well known examples of ESTs used for good water management and wasted water reduction in domestic, agricultural, and industrial sectors. To the best of our knowledge there is still no study related to the implementation of WSDs in order to contribute to water conservation before, in the whole of West Africa. Niger is no exception.

The main aim of this work is to characterize the phenomenon of water waste in Niamey hotels, identify efficiency requirements for mitigation against it, and develop a smart WSD system for ICT-based and mitigation-driven shower water management in Niamey hotels.

II Justification of the Study

Due to multiple factors, such as climate change and urbanization combined with population growth, especially in urban areas, water stress is generally expected to increase significantly worldwide by mid-century, particularly in Africa, Asia, Australia, New Zealand, and Southern Europe, as well as Latin and North America (IPCC, 2007; Chang et al., 2013). Therefore, the study of water management and conservation becomes an important research issue.

"There are two main categories of water saving measures to reduce water use: technical measures including network improvement, repair leaks, developing water-efficient appliances; and non-technical measures covering information, education, awareness that may change consumptive habits" (Yang et al., 2017).

This work focuses on the non-technical measures including the application of ESTs. The definition of Environmentally Sound Technologies (ESTs) is based on Agenda 21, which arose from the United Nations Conference on Environment and Development (UNCED), otherwise known as the Earth Summit, held in 1992 (Halls, 2015). Chapter 34 of Agenda 21 defines ESTs as technologies that:

- have the potential for significantly improved environmental performance relative to other technologies;
- are less polluting;
- **use resources in a sustainable manner (where the goal is zero waste and/or significant reductions in resource use);**
- recycle more of their wastes and products, and
- handle all residual wastes in a more environmentally acceptable way than the technologies for which they are substitutes.

Out of ESTs to protect the environment, WSDs are those used for sustainable resources such as water, energy, etc. Indeed, WSDs sustain demands for potable water, soften impacts on supply systems and inflict a positive effect on waste water treatment systems (Rahman et al., 2016).

Thus, this applied research will focus on the assessment of shower water use by guests in Niamey hotels and then, the development of a smart WSD system in order to reduce shower water waste in Niamey hotels.

III Research questions, hypotheses, and objectives

In order to well conduct this research, a main research question, a main hypothesis, and a main objective are set with three (3) specific research questions, three (3) hypotheses, and three (3) objectives respectively.

III.I Research questions

To well guide this applied research, the main research question is formulated as follow:

Can shower water waste in Niamey hotels be efficiently reduced by the development of a smart water-saving device system?

The specific research questions are:

i. Can the daily average amount of showering water per guest in Niamey hotels be estimated?
ii. What should be the efficiency requirements for water waste mitigation that a smart WSD device system should meet to be able to reduce shower water use in Niamey?
iii. How can this smart device system be developed to user-friendly manage shower water use in Niamey hotels with respect to the efficiency requirements?

III.II Research hypotheses

The main research hypothesis is:

The development of a smart water-saving device system can contribute to reduce efficiently shower water waste in Niamey hotels.

The specific research hypotheses are:

i. The daily average amount of showering water per guest in Niamey hotels can be estimated;
ii. Efficiency requirements can be proposed to contribute to the mitigation of shower water waste in Niamey hotels;
iii. A user-friendly smart device system can be developed to manage shower water use in Niamey hotels with respect to efficiency requirements.

III.III Research objectives

To accomplish this applied research, the main research objective is settled as follow:

To develop a smart water-saving device system for reducing efficiently shower water waste in Niamey hotels.

The specific research objectives are:

i. To collect water consumption data from some representative hotels then estimating the daily average amount of showering water per guest.
ii. To propose efficiency requirements for water waste mitigation that a smart WSD device system should meet to reduce shower water waste in Niamey.
iii. To develop a smart device system that will user-friendly manage shower water use in Niamey hotels with respect to the efficiency requirements.

CHAPTER 1: LITERATURE REVIEW

This chapter presents a review of literature pertinent to the research. Various water consumption systems in different cities are outlined. Different water consumption reduction systems are presented from both the domestic and the industrial sectors. Finally, a review of ESTs including a short history, the relation between ESTs and sustainable development, and the description of some kind of ESTs (i.e., WSDs used for shower water waste reduction) is provided.

1.1. Water consumption in Cities

Many cities in the world are expected to face fresh water shortages in the future due to population growth combined with urbanization and the related decline in renewable fresh water resources caused by the effects of climate change. The urban area, including. Globally, all sectors (agricultural, industrial, domestic, etc.) contribute significantly to the exploitation of global fresh water resources (Schuetze & Santiago-fandiño, 2013) with the cities and urban areas being places where these fresh water resources are overexploited. For instance, in Australia, in Gold Coast (a city of 0.5 million) an amount of 185 mega liters per day (ML/D) is consumed, which is equivalent to 67,525 ML/D per year, and represents 66% of the global water consumed in the city (Willis et al., 2013). In India, it is stated that the water utilization in urban areas is more than that of rural areas as people living in urban areas fully depend on the municipality water supply (Hota, 2014). In U.S.A, the average daily water flux per person is estimated at 560 L of drinking water and 500 L of wastewater (Nexus, 2018). By 2050, it is predicted that 67% of the world population is expected to be living in urban areas with the most rapid levels of urbanization taking place in African countries (Cullis et al., 2019). Thus, a large amount of water will be wasted in those areas. According to Ayeni et al. (2016), the Lagos State population in Nigeria is expected to increase to about 19.8 million causing a rise of required water to 2418.9 ML/D by the year 2026. In Niamey, the capital of Niger, the annually water consumption is increasing exponentially. Indeed, the annual amount of water consumption in Niamey city was 34,054 Mm^3 (Million cubic meters), 36,554 Mm^3, and 38,484 Mm^3, in 2015, 2016, and 2017 respectively (*Republique Du Niger*, 2018). Different factors can influence water demand. As shown in **Fig. 1**, climate change, demographics, land use, and water use practices and equipment are among the key factors affecting water consumption.

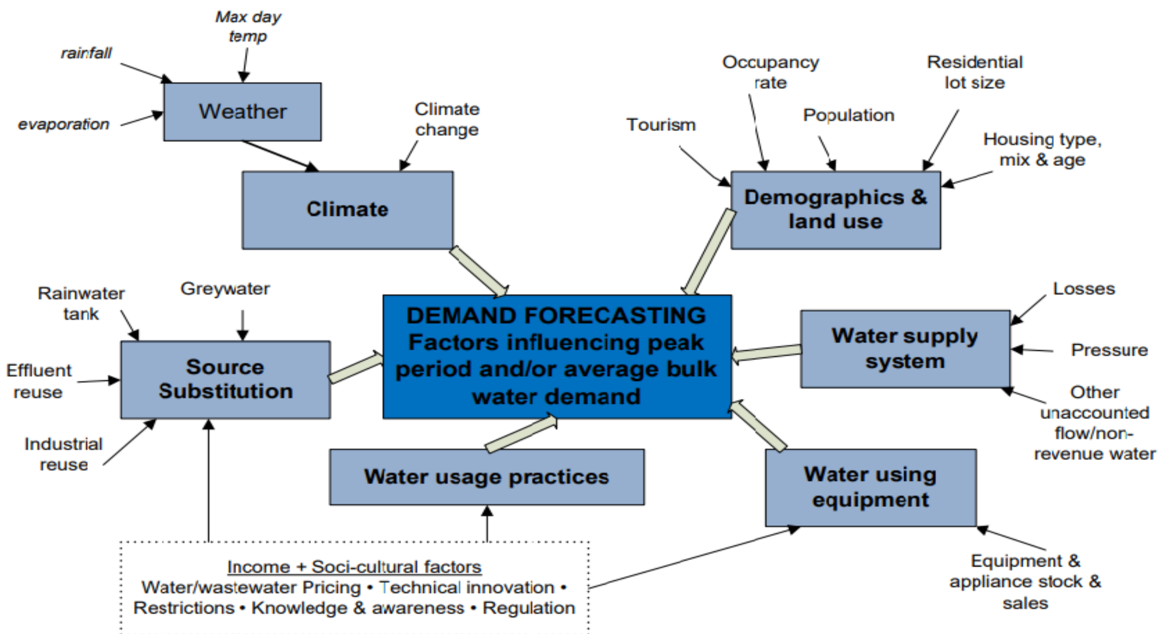

Figure 1: Factors that influence water demand (White and Turner, 2003; WSAA, 2008; Rachelle, 2011).

1.2. Water consumption reduction in domestic sector

In a study entitled: "***Assessment of water-saving equipment to support the urban management of water"***, Alegre et al. (2017) have developed a methodology to establish the index of water consumption reduction for the domestic category. They calculated the water consumption for each equipment installed using the following formula below:

$$CAC_i = DCA_i \times CMR \quad (1.1)$$

Where:

CAC_i = mean monthly consumption of conventional equipment i (m^3/month);

DCA_i = distribution of water consumption per sanitary equipment i;

CMR = mean monthly consumption for each area of Caruaru (m^3/month).

Then, through the equation (1.2), the water consumption for each water-saving equipment was established.

$$CAP_i = (1 - F_r) \times CAC_i \tag{1.2}$$

Where:

CAP_i = monthly consumption with the implementation of water-saving equipment (m^3/month);

F_r = factor of reduction of water consumption per sanitary equipment (data provided by the manufacturer representing the ratio between the flow of water-saving equipment and the conventional one as shown in Table 1.1.

Finally, the saving of water is calculated using equation (1.3) as follows:

$$EDA_i = CAC_i - CAP_i \tag{1.3}$$

1.3. Water consumption reduction in industrial sector

For the industrial sector, the case of hotels is presented in this work. Indeed, to achieve sustainability in the future, the efficient management of water resources by the industrial sector is essential. It’s in this sense that Tirado et al. (2019) felt that: "Hotels, together with other tour operators, have a responsibility not to use more water than is absolutely necessary"**.**. However, to detect and analyze the potential variables that influence the degree of adoption of water-saving measures, they applied a method called the "***Ordered Probit model*** "**.** Also, they classified the water-saving measures into two (2) categories:

(i) the basic category including many examples of these kinds of water-saving measures such as: flow restrictor and aerators on faucets, maintenance of plumbing fixtures and devices, sink stoppers that seal properly, low-flow showerheads, water displacement toilet devices, etc.

(ii) the advanced category including water-saving measures such as: the control of water losses in the water supply and distribution network, monitoring and metering water in different departments or areas, optimization of irrigation systems in garden, recycled water (from the laundry, kitchen, air conditioning, pool backwash, or chilling tower blow-down water), etc.

This method which allowed them to identify the main variables that are related to water-saving measures introduced in the hotels is formulated as follow:

The dependent variable consists of $j = 1, \cdots J$ mutually exclusive categories in a natural order. For each case, only one of the categories is observed according to:

$$y_i = j \text{ if and only if } \gamma_{j-1} < y_i^* \leq \gamma_j \quad j = 1, \cdots J \tag{1.4}$$

Where $\boldsymbol{\gamma_j}$ indicates different thresholds, which are unknown, except for $\boldsymbol{\gamma_0} = -\infty$ and $\boldsymbol{\gamma_j} = \infty$. $\boldsymbol{y_i^*}$ is a latent variable, which can be specificied according to $\boldsymbol{y_i^*}=x_i'\beta + u_i$. In this application, the latent variable captures the willingness to implement water-saving measures. As the latent variable increases, the number of implemented measures also increases as another threshold is reached. The probability of observing option j is:

$$\Pr(\boldsymbol{y_i} = j|x_i) = p_{ij} = F\left(\boldsymbol{\gamma_j} - x_i'\beta\right) - F\left(\boldsymbol{\gamma_{j-1}} - x_i'\beta\right) \quad j = 1, \cdots J \tag{1.5}$$

Where:

$F(\cdot)$ is an accumulated function, and using the accumulated standard normal distribution function, $\Phi(\cdot)$, implies an Ordered Probit model. It is necessary to estimate $\boldsymbol{\gamma_j}$, $j = 1, \cdots J, J-1$ thresolds, apart from the parameters, β.

As well known, fresh water resources are being overused in almost all cities around the world (Goulden & Few, 2011). Decision makers such as international institutions, governments and others stakeholders are doing all their best to reduce water waste. Fortunately, ESTs are now existing technologies that can be used to reduce the waste of fresh water resources especially in cities.

1.4. Environmetally Sound Technologies (ESTs)

1.4.1. A short history on ESTs

As already said in the introduction part, the definition of Environmentally Sound Technologies (ESTs) is based on Agenda 21, which arose from the United Nations Conference on Environment and Development (UNCED), otherwise known as the Earth Summit, held in 1992 (Halls, 2015). However, ESTs are not just individual technologies. They can also be defined as total systems that include know-how, procedures, goods and services, and equipment, as well as organizational and managerial procedures for promoting environmental sustainability.

For several decades ago, little progress has been made in the trade of ESTs without the participation of developing countries. However, since 2006, with the participation of developing countries, trade in ESTs is making significant progress, but it's still dominated by developed countries and emerging economies. The figure below (**Fig. 2**) shows the evolution of trade in ESTs from 2006 to 2016.

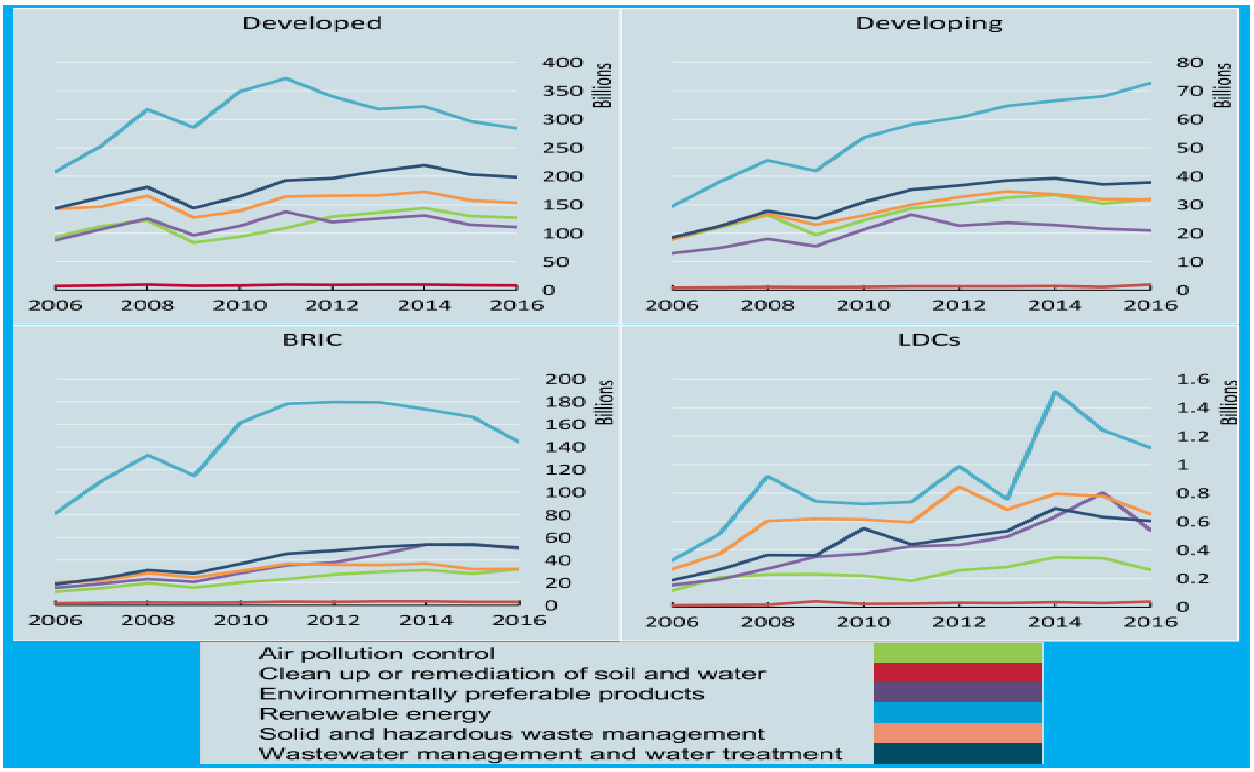

Figure 2: Trade in selected ESTs: from 2006-2016.

Source: (Less & Mcmillan, 2005)

1.4.2. ESTs and Sustainable development

The United Nations World Commission on Environment and Development has defined sustainable development as development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Kumar et al., 2020).

The transfer through trade, adoption, and use of ESTs could help to reach some specific sustainable development goals among the 17 specified by the United Nations (UN) (Approach et al., 2013). For that, clear policies are needed from governments, communities, and other stakeholders which should work together to facilitate the realization of sustainable solutions. According to the figure below (**Fig. 3**), throughout the transfer of ESTs among countries, many goals of sustainable development could be reached.

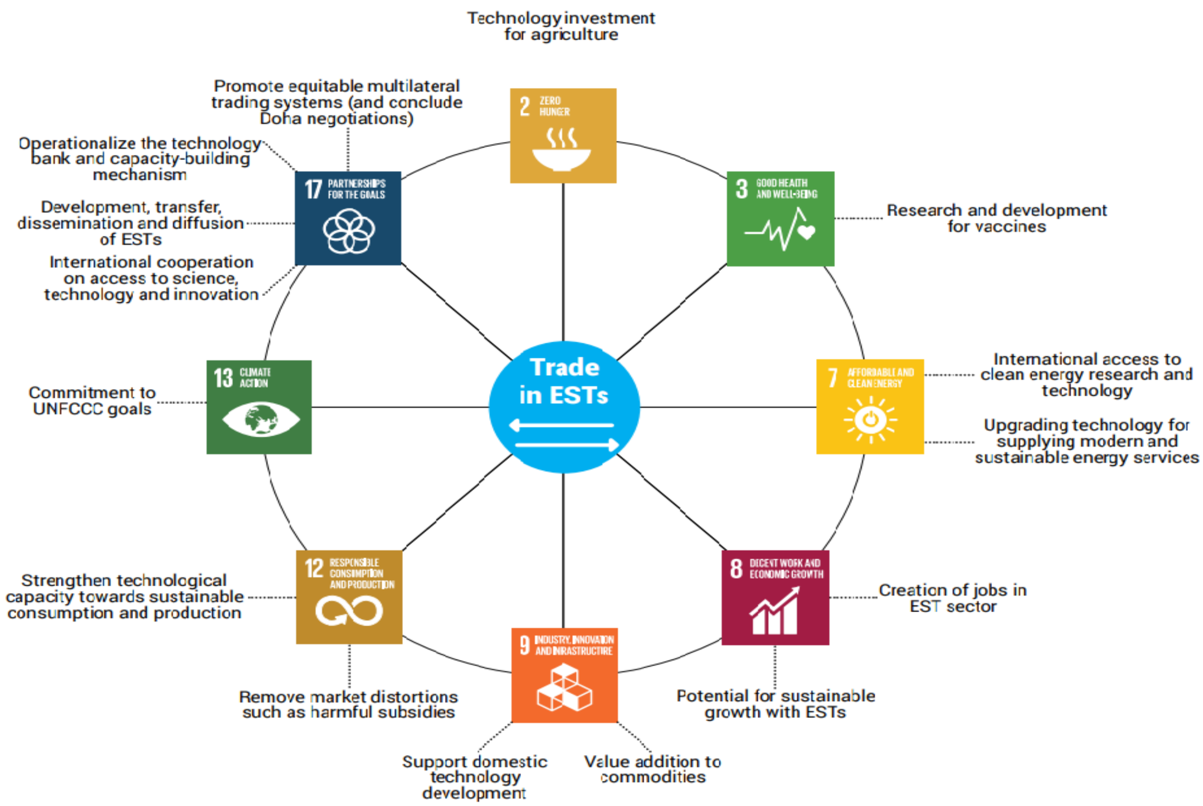

Figure 3: World Trade Organization (WTO) database on trade in services, country- and company-level data, as well as scientific publications.

Source: (UNEP, 2018).

The figure below (**Fig. 4**) outlines the principal characteristics of ESTs and their relation with sustainable development. Environmental sustainability considers the protection of ecosystems and resources. Economic sustainability considers operating and maintenance costs as well as long-term productivity. Social and cultural sustainability considers health protection and the preservation of social and cultural values.

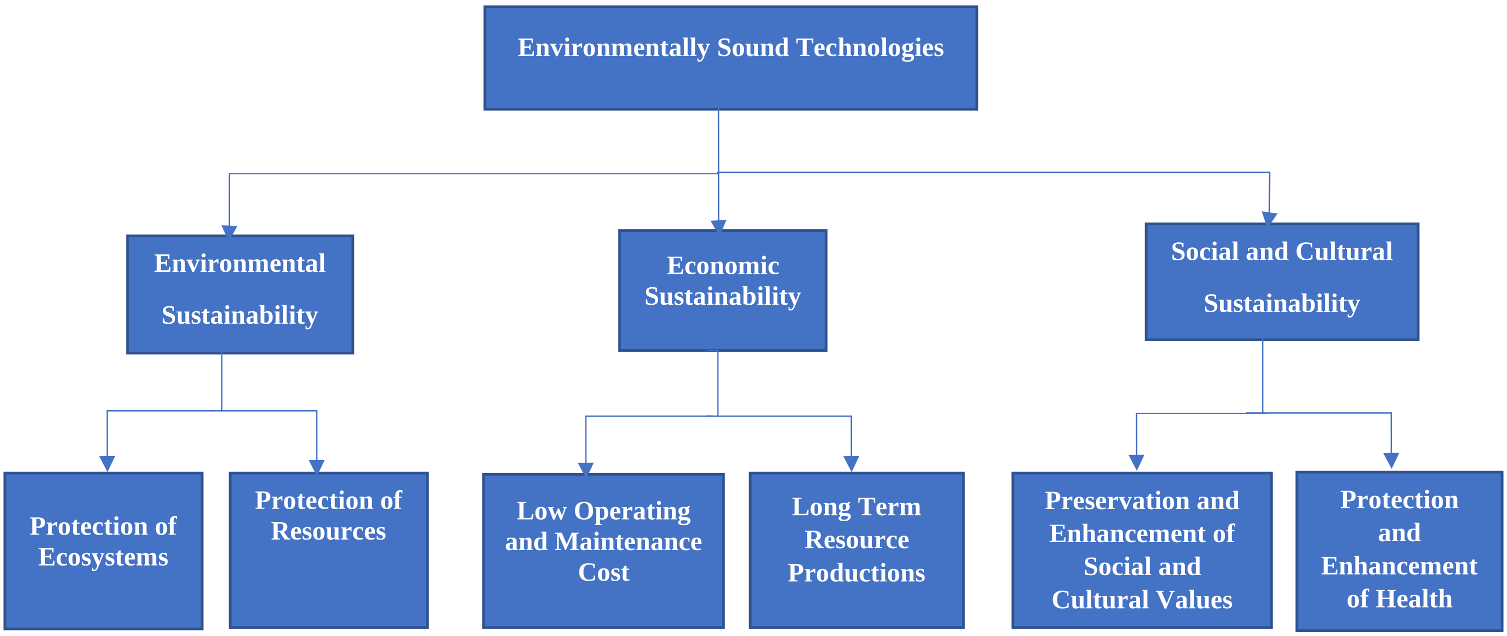

Figure 4: Characteristics of ESTs in Relation to Sustainability.

Source: (Salazar, 2021).

1.4.3. Barriers/Challenges for the transfer of ESTs in developing countries.

Through its International Environmental Technology Centre (IETC), the United Nations on Environmental Protection (UNEP) has defined a lot of barriers to EST transfer, especially in developing countries (Luken & Rompaey, 2008). Among those barriers exist:

- The inadequacy of information and decision support tools used to quantify and qualify the merits of ESTs and related investments.
- The challenge is even greater in the context of developing countries, given the complexity of factors that influence and determine investment decisions.
- Inadequacy of information and decision support tools represents a significant challenge.
- Governments, the private sector, and citizens are not coordinated in their activities.

- Lack of systems for collecting, synthesizing, and feeding back information and knowledge on ESTs. These must be developed and maintained.

However, in developing countries, the transfer of ESTs was reported to be possible through foreign direct investment (FDI), which depends on market-based mechanisms as well as regulatory instruments, such as incentives, market access, environmental policy, etc. (Kumar et al., 2021b).

Nevertheless, the transfer of ESTs in African countries still faces some challenges. Thus, among the top-10 developing country exporters of ESTs goods (see **Fig. 5**) from 2006-to 2016 in the world, South Africa (7th position) is the only African country (Hub, 2019). It has also been reported that as importers of ESTs, no African country exists among the top-10. Indeed, the challenges of the transfer of ESTs in African countries is a reality.

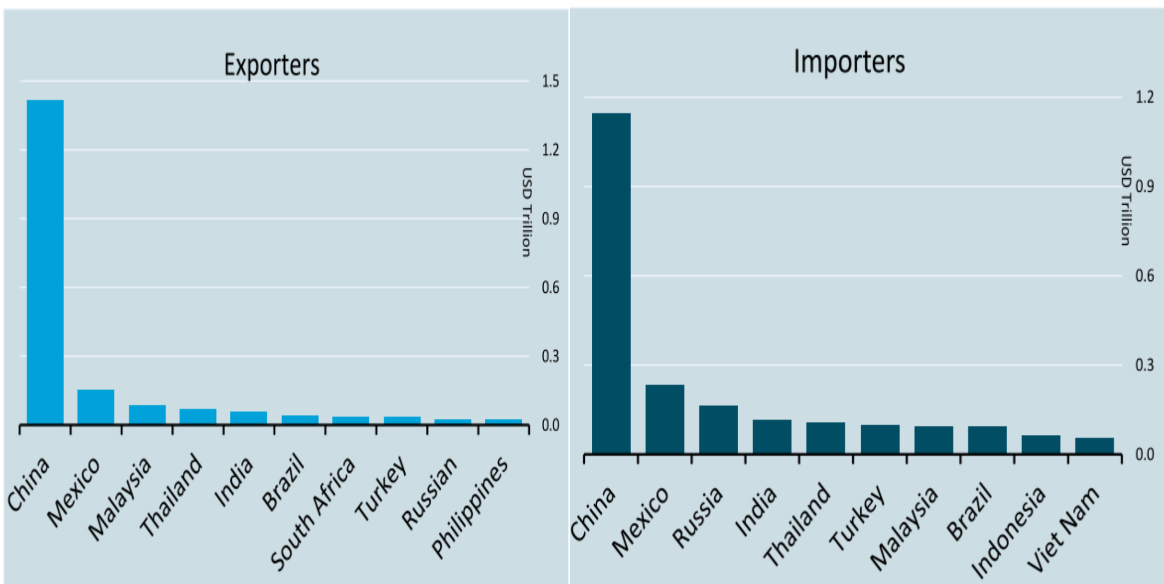

Figure 5: Top-10 developing country importers and exporters of ESTs good over 2006-2016.

Source: (Hub, 2019).

1.4.4. Criteria for the adoption, implementation and use of ESTs

Criteria can be defined as principles or standards against which something is judged. They must be considered as part of a dynamic process because they reflect a certain bias based on previous experience and expectations. So, for the identification and selection of ESTs in a consistent manner with sustainable development objectives, appropriate criteria are needed. However, the usefulness of these criteria will be limited if a clear definition and understanding of the specific context in which they are applied aren't well known. The following table (**Table 1**) shows two (2) important generic environmental criteria and guidelines that can be used in the assessing and evaluating of ESTs (Halls, 2015).

Table 1: Generic Environmental Criteria and Guidelines for Assessing ESTs Criteria.

Criteria	**Guidelines**
✓ Sustainable resource development and utilization	• Plans for the sustainable resource development and use have been developed • Expenditures on sustainable resource development and utilization have been considered • Expenditures on sustainable resource augmentation (i.e. reforestation) have been considered
✓ Protection of freshwater quality and supply	• Annual withdrawals of ground and surface water and water consumption have been determined • Opportunities for water conservation and efficiency improvements have been determined • Potential sources of water pollution have been determined • Plans and facilities for water and wastewater treatment and hydrological monitoring are in place • Expenditures on water and wastewater treatment have been considered

The implementation of ESTs requires the participation of policies and programs which integrate the elements of capacity building, information and knowledge into comprehensive approaches for EST transfer and cooperation. They can achieve more than individual actions, and can participate to the creation of an innovative culture. However, this involves the participation to the development process of public and private stakeholders, including business, legal, financial, and within both developed and developing countries.

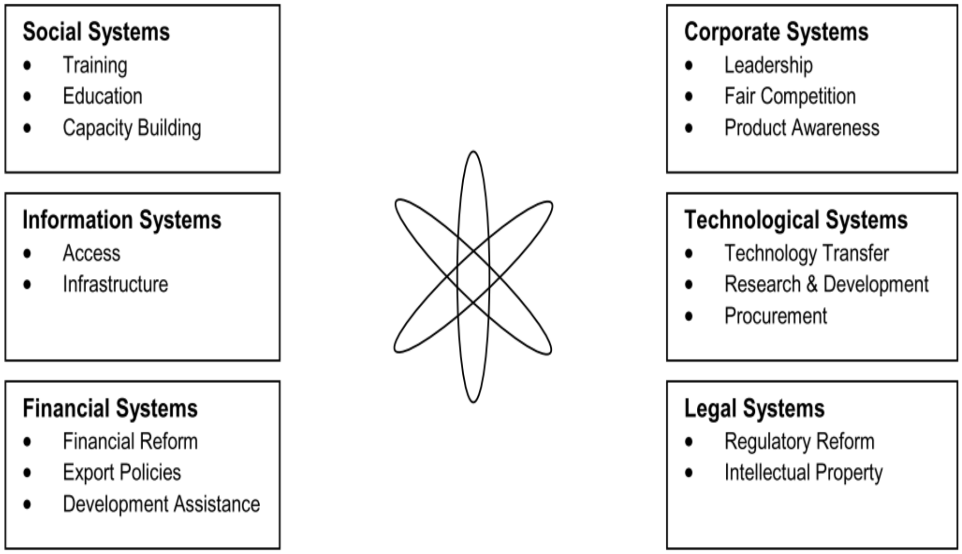

Figure 6: Framework for the Implementation of EST Policies and Programs.

1.4.5. Evaluation of WSD implementation in domestic and hotels sectors

Whether in domestic sector, university campus or in hotels, shower is a place where a large amount of water is wasted by users every day. Australia is one of the countries most affected by a lack of drinking water. Indeed, for several years, the Australian government has been implementing several strategies to assess the water consumption of the population and to assure a moderate consumption of that scarce resource. Makki et al. (2013) studied the determinants of shower water use end consumption. His study revealed that females, children in general and teenagers in particular, and the showerhead efficiency level were statistically significant determinants of shower end use consumption.

In a study, Schuetze & Santiago-fandiño (2013) stated that in standard households, more than 50% of the total domestic water is consumed via taps and showerheads. Moreover, they evaluated the domestic water consumption for different needs in three countries say the Netherlands, Germany (Hamburg), and South Korea (Seoul). The obtained data are illustrated in the following table 2.

Table 2: Domestic water use for different applications in the Netherlands, Germany (Hamburg), and South Korea (Seoul), in L per capita per day, and percentages of total water consumption.

Country/City	**Domestic water consumption In L per capita per day (High quality standards)**			**Service water quality Sufficient (Low quality standards)**			**Total**	**Service Water sufficient**	**Drinking Water required**
Purpose	**Cooking and drinking**	**Washing (kitchen)**	**Bath and shower**	**Laundry**	**Cleaning and watering**	**Toilet flushing**			
Netherlands	**8.8 L**	**6.8 L**	**52.3 L**	**17.2 L**	**5.3 L**	**37.1 L**	**127.5 L**	59.6 L	67.9 L
% Of total	6.9%	5.3%	41.0%	13.5%	4.2%	29.1%	100.0%	46.7%	53.3%
Germany (Hamburg)	**5 L**	**8 L**	**46 L**	**15 L**	**8 L**	**35 L**	**117 L**	58 L	59 L
% Of total	4.3%	6.8%	39.3%	12.8%	6.8%	29.9%	100.0%	49.6%	50.4%
South Korea (Seoul)	**12 L**	**22 L**	**80 L**	**20 L**	**8 L**	**66 L**	**208 L**	94 L	114 L
% Of total	5.8%	10.6%	38.5%	9.6%	3.8%	31.7%	100.0%	45.2%	54.8%

The above table shows that bath and shower represent 41.0% (52.3L), 39.3% (46L), and 38.5% (80L) of domestic water consumption per capita per day in the Netherlands, Hamburg (Germany), and Seoul (South Korea), respectively. Thus, one can confirm that shower is in reality a place where water is wasted.

Nowadays, there are dozens or even hundreds of hotels in major cities. However, hotels are places in cities where a significant amount of water is consumed every day around the world. This is due to the fact that: "most hotels do not monitor individual guest water usage and as a result, millions of gallons of potable water are wasted every year by hotel guests" (Hawrylak et al., 2015).

For quite a long time, the Sultanate of Oman is facing fresh water resources shortage. The annual water demand is about 1645 Mm^3 (Million cubic meters) while the water resources of the Sultanate are estimated at 1267 Mm^3, resulting in an annual water deficit of 378 Mm^3 (Rahman et al., 2016). To overcome this issue, the evaluation of some WSD has been conducted in the Sultanate of Oman in order to see how they can contribute to reduce water waste. After their installation, the study confirmed that water-saving devices were significantly effective in restaurants, mosques, hotels and government buildings. For example, Holiday Inn, a hotel of 123 rooms in total has been chosen to install water-saving devices. The figure below (**Fig. 7**) shows the water consumption before and after WSDs installation in this hotel.

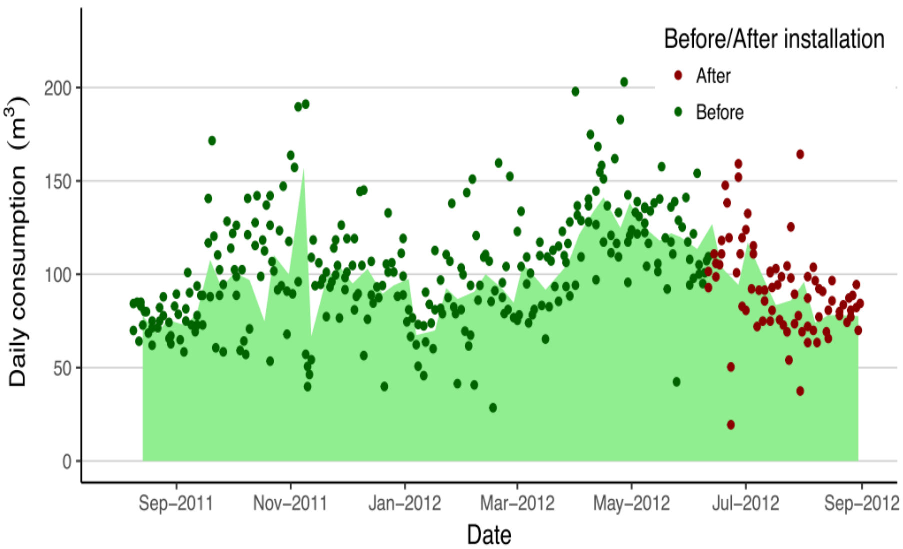

Figure 7: Daily water consumption at the Holiday Inn Hotel before and after installation of water saving devices (WSDs).

Source: (Rahman et al., 2016).

A descriptive statistics method has been used to determine water consumption before and after WSDs installation. It showed that the mean weekly consumption before installation was 711.98 m^3. It decreased to 633.47 m^3 after the installation of the WSDs.

1.5. WSDs applied for shower water waste reduction

1.5.1. Acqua Tempus

Easy to install and easy to use, the user just has to program the maximum time he/she wants to give for each shower and once this time has passed it shuts it off and the pre-set waiting time begins (the minutes that have to go by till the next shower is available). Therefore, the user has to abandon the shower saving a lot of water and energy. The shower timer has a solenoid valve inside and a lithium battery that is charged by to a water turbine inside the Acqua Tempus that generates power when the water is flowing through. So, no plumbering or electrical connections are needed. With hardly any installation, we can start saving a lot of money in our home or hotel just by restricting the maximum time for showers, educating people to practice a responsible consumption of water. Acqua Tempus (**Fig. 8**) has a **water leak sensor: in case the user leaves the tap open, Acqua Tempus** will automatically shut the tap to stop any water waste.

Figure 8: Showing Acqua Tempus device.

The Acqua Tempus is a very high WSD technology used in showers. It's a finished product and is already on the market. Although it's a device designed to reduce water waste in showers, it still has some shortcomings such as:

- it doesn't allow to limit the daily shower water consumption per capita;
- it can't allow to know who saves or wastes water while showering and no shower water data storage.

1.5.2. Show-me

Show-me stands for shower water meter. It is a device that measures the amount of water that is being used during a shower. The show-me prototype (Fig. 1.9) consists of a flow meter (AMess), a prototype board (Olimex), a microcontroller (Atmel) and 16 LEDs assembled on a stick. For each liter of water flowing through the meter, one tick is sent to the microcontroller. This information is converted into LEDs lighting up according to a factor that can be set by the user. The amount of water that is needed for one LED to light up is equal to 5 liters. To test the device, the **show-me** prototype has been installed in four households with nine occupants (four females) including one child. After a period of 3 weeks of test, the results show that the mean water consumption decreased by approximately 10 liters per day for each user (Water, 2016).

Figure 9: Show-me device prototype.

Source: (Water, 2016).

As shortcomings of the show-me device:

- It can only display values that are multiples of 5;
- it doesn't show to the user the amount of water consumed which isn't a multiple of 5;
- it can't limit the daily shower water consumption per capita;
- it doesn't allow to know who saves or wastes water while showering;
- it doesn't have any shower water data storage device.

1.5.3. Domestic water consumption monitoring and behavior intervention by employing the internet of things technologies

This work presented the achievements of monitoring domestic water consumption at the appliance level and intervening people's water usage behavior which have been made in ISS-EWATUS, a European Commission funded FP7 project (**Fig. 10**). The water amount consumed by every household appliance is wirelessly recorded with the exact consumption time and stored in a central database. People's water consumption behavior is likely affected by the real-time water consumption awareness, instant practical advices regarding water-saving activities and classification of water consumption behavior for individuals, all of which are provided by a decision support system deployed as a mobile application in a tablet or any other device.

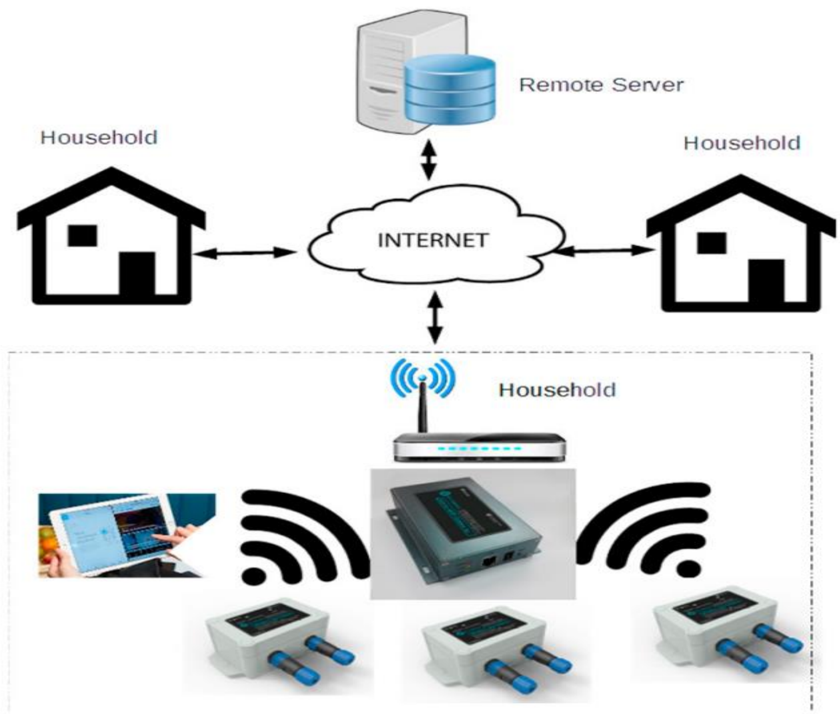

Figure 10: System architecture.

This WSD system is a good tool for shower water waste reduction and for data storage, but needs external power supply to work and can't limit the daily shower water consumption per capita.

1.5.4. The connected Shower

The **Connected Shower** (Fig. 11) is a bespoke IoT device that captures water flow, temperature, shower-head movement, and shower product weight. This device has been deployed in six UK homes/households for a week to understand the use of 'intimate data' as captured by IoT systems. Each of the six households is consisting of an adult male-female couple, one household also had a one-year-old baby. Over the long-week deployment of the device, participants in different households had a varied range of shower use. The range was from 2 to 10 minutes on the average, each consuming between 21 to 145 liters on average.

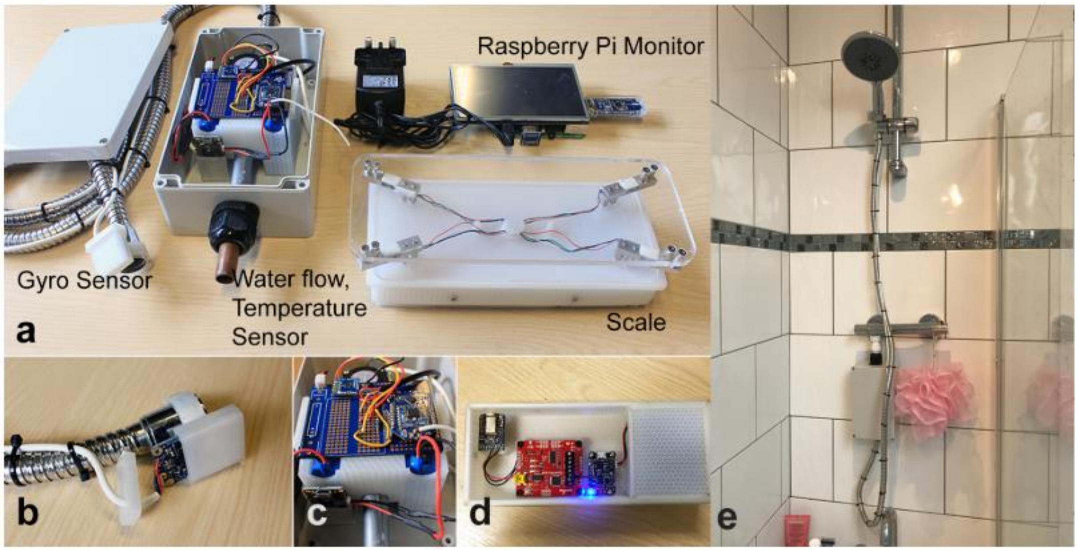

Figure 11: (a-d): (a) Overview of components of the kit, and closed-up view of (b) gyro sensor, (c) water flow and temperature sensor board, (d) Bluetooth-enabled weight sensing board connected to 4 load cells on the scale, (e) IoT shower kit in.

The connected shower has limits such as:

- it needs an external power supply to work;
- it can't limit the daily shower water consumption per capita.

So, the users can continue to waste water in showers despite its installation.

1.5.5. HydroSense

HydroSense (**Fig. 12 and Fig.13**) is a novel low cost, accurate, small size, low power, wireless device for monitoring water use from hotel room showers. It is targeted for the hotel industry to reduce costs by promoting water conservation among hotel guests.

Some characteristics of **HydroSense** are listed below:

- The flow meter should minimally obstruct the flow of the water;
- The flow meter transmits data wirelessly to a central hotel computer

- The flow meter measures the flow rate in range of 4.73 to 18.93 liters per minute (lpm) (which is equivalent to 1.25 to 5.0 gallons per minute (gpm));
- The device is operated by a low level of power;
- The device is self-powered by either the water running through it or by solar energy;
- The device requires very little to no maintenance.

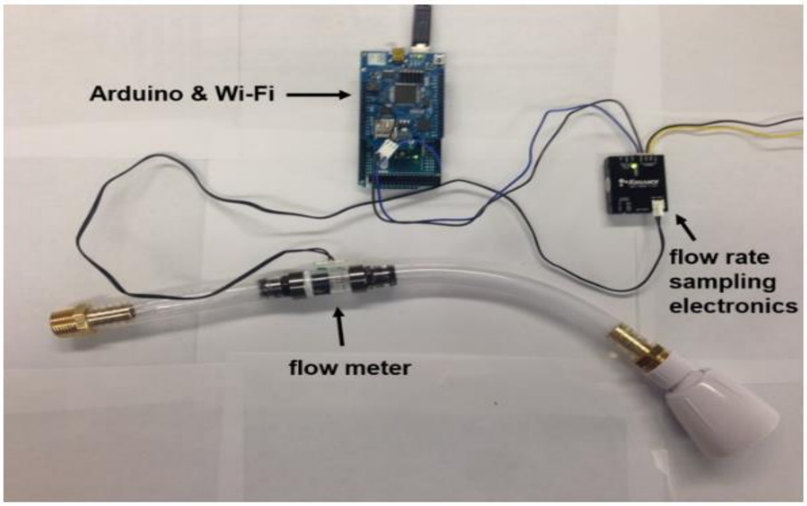

Figure 12: HydroSense prototype.

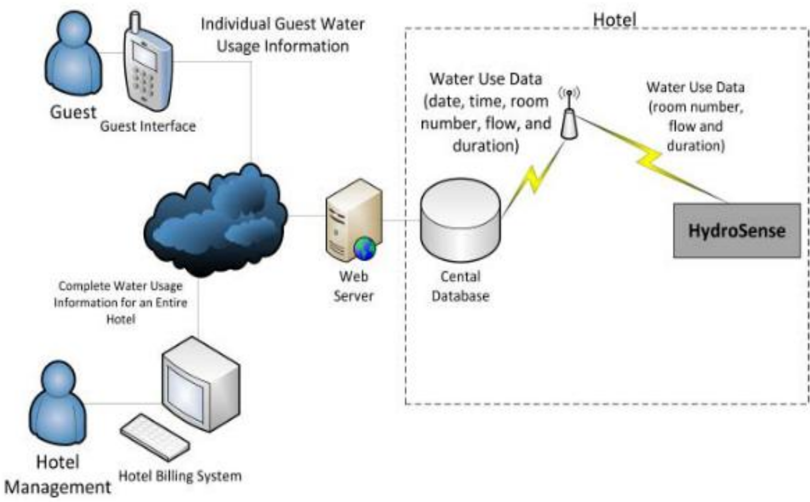

Figure 13: Dataflow between HydroSense and the hotel.

The HydroSense is probably one of the best WSD to reduce water waste in hotel rooms. Unfortunately, it has some shortcomings since hotel guests/clients can continue to use water in shower as they want without any restrictions.

CHAPTER 2: MATERIALS AND METHODS

2.1. Study Area

Niamey has been chosen as study area to conduct this work in Niger. The reason is that Niamey being the capital has more hotels than all the others cities in Niger. Located in the south of the Sahara and in the heart of the Sahel, Niger covers an area of 1,267,000 km^2. It is bordered to the west by Mali and Burkina Faso, to the south by Nigeria and Benin, to the east by Chad and to the north by Algeria and Libya. It is a landlocked country with the nearest port (Gulf of Guinea) being about 700 km far from the capital Niamey. The relief in Niger is characterized by low altitudes (200 to 500 m), and some very old mountainous massifs in the northwest (Aïr massifs). The country's climate is tropical arid and semi-arid. Niger is indeed located in one of the hottest areas of the world. There are four (4) types of seasons: a cold season (December to February), a hot dry season (March to May), a rainy season (June to September) and a hot season without rain (October to December). Record minimum and maximum temperatures in Niger were -2.4°C (observed on January 13, 1995 in Bilma) and 49.5°C (observed on September 7, 1978 in Diffa) respectively (Climatiques, 2016). Niger is subdivided into three distinct sub-climatic zones such as: desertic or Saharan zone, intermediate zone (largely pastoralist), and semi-arid zone (Potsdam Institute and GIZ 2021; Idoukal-n-taghes et al., 2022). Despite the fact that the country is arid and semi-arid, its potential in water resources is important. They are made up of rainfall, surface and ground water. In particular, Niger's surface water resources are globally very important (more than 30 billion m^3/year) of which only 1% is exploited. However, these water resources that the country able to exploit. should be well managed and not wasted.

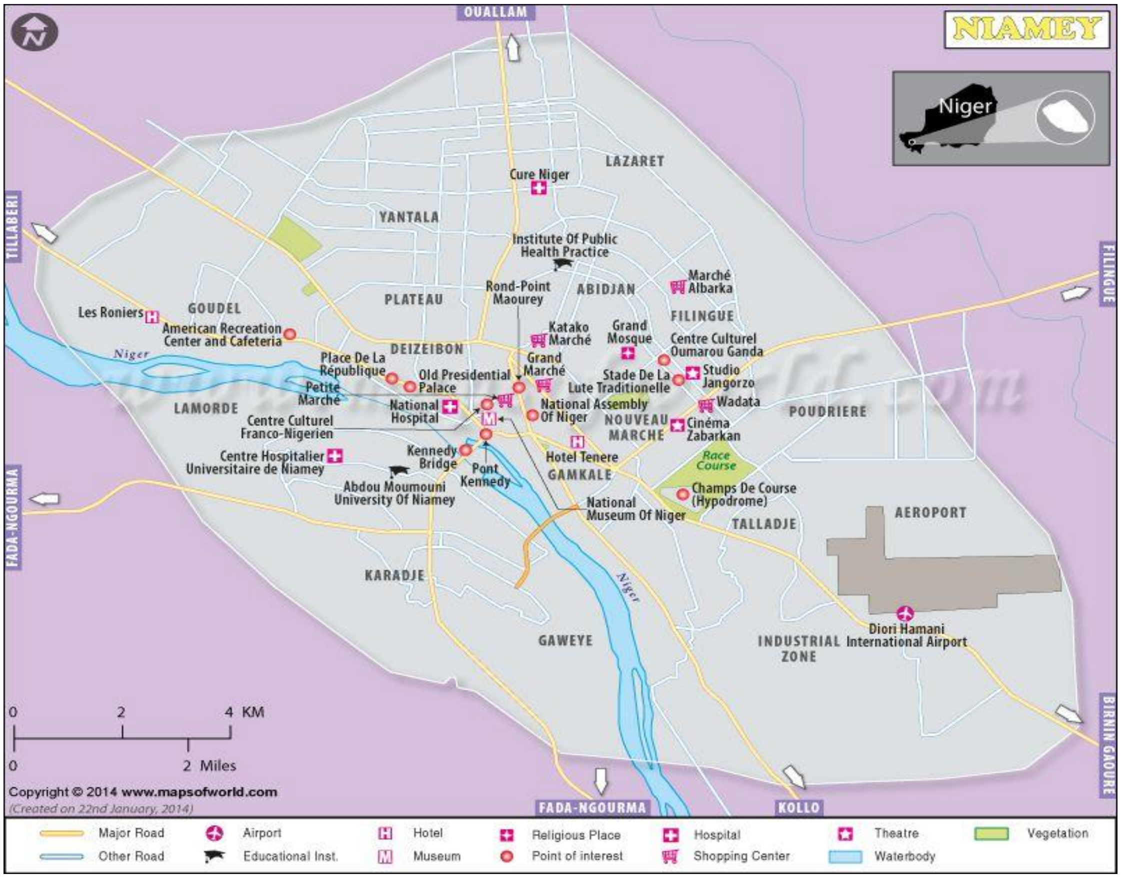

Figure 14: Map of Niamey City, NIGER.

Source: *(Market in Niamey, Niger Source: Http://En.Loadtr.Com/21_Niamey_Niger- 423880.Htm, 2018).*

2.2. Data Collection

Two on-site surveys were carried out to get the data needed to reach the different objectives of this thesis: the first one was conducted at the *Direction Regionale du Tourisme et de l'Artisanat (DRTA)* of Niamey, and the second one submitted to the hotel sector.

The following questions (in French) were posed to the DRTA:

1. What is the total number of hotels in the city of Niamey for the years 2019, 2020, and 2021?
2. What is the total number of guest rooms in the hotels for the year 2019, 2020, and 2021?
3. What is the total number of guest beds in the hotels for the year 2019, 2020, and 2021?

Afterwards, an on-site survey was conducted to collect sample data from 17 hotels. The following ten (10) questions (in French) were submitted to the different hotels:

1. Is your hotel certified green or not?
2. What is the number of rooms in your hotel?
3. How many beds do you have for guests?
4. What is the occupancy rate of the rooms?
5. Have you installed a water saving device in the showers of your hotel? If yes, what type?
6. Are there any efficiency requirements applied in your hotel to reduce shower water waste? If so, what are they?
7. Are you able to monitor/control the daily shower water consumption of each guest/room in your hotel? If so, how?
8. What is the percentage of shower water consumption by guests compared to the overall water consumption in your hotel?
9. What factors/parameters increase shower water waste in your hotel?
10. If available, can we have data on water consumption in showers in your hotel for the years 2019, 2020, and 2021? If not, then can we have the total monthly water consumption data for the years 2019, 2020, and 2021, copies of your bills for example?

2.3. Materials and Tools

Many tools/materials were used for the purpose of this applied research. Especially open-source tools and materials such as electronics components were used for the design and implementation of the smart WSD system.

2.3.1 Tools

The following tools are used:

- **Microsoft Excel Worksheet** was used to store data and information collected during surveys.
- **MATLAB** is a fourth-generation high-level programming language and interactive environment for numerical computation, visualization and programming. It allows matrix manipulations, plotting of functions and data, etc. It was used in this work for data analysis and for numerical computation.

- **Arduino Integrated Development Environment (IDE)** is a software that contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions and a series of menus. It connects to the Arduino hardware to upload programs and communicate with them. So, it was used in this work for the implementation of a code and its uploading in the designed smart WSD.
- **ThingSpeak** is an open data platform for the Internet of Things (IoT). Your device or application can communicate with **ThingSpeak** using a RESTful API. In this work, it was used for data collecting after someone used the smart WSD. The latter will automatically send some data to **ThingSpeak.**
- **Mendeley Software** is a reference manager and academic social network that can help you organize your research, collaborate with others online, and discover the latest research. More specifically, it was used to automatically cite references and generate bibliographies when writing this thesis.
- **Microsoft Word on Windows** was used to write the report of this thesis.

2.3.2 Electronics Components used to design the smart WSD system

The smart WSD designed for the purpose of this work is a multifunctional device which required a lot of materials. The name, description, and reason of choice of each equipment are listed below:

- **Arduino Microcontroller**

Arduino is an open-source electronics platform based on an easy-to-use hardware and software. Arduino boards are able to read inputs (light on a sensor, a finger on a button, etc.) and turn it into an output (publishing data online). You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so, you use the Arduino programming language (based on wiring), and the Arduino software (IDE), based on processing. It exists different types of Arduino boards: Arduino Nano, Arduino Due, Arduino Pro mini, Arduino Uno, Arduino Mega, etc.(arduino.cc website)

For our WSD system, Arduino Mega 2560 (Fig2.2) was used because of its large number of pins as many sensors are needed to design the targeted system. The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

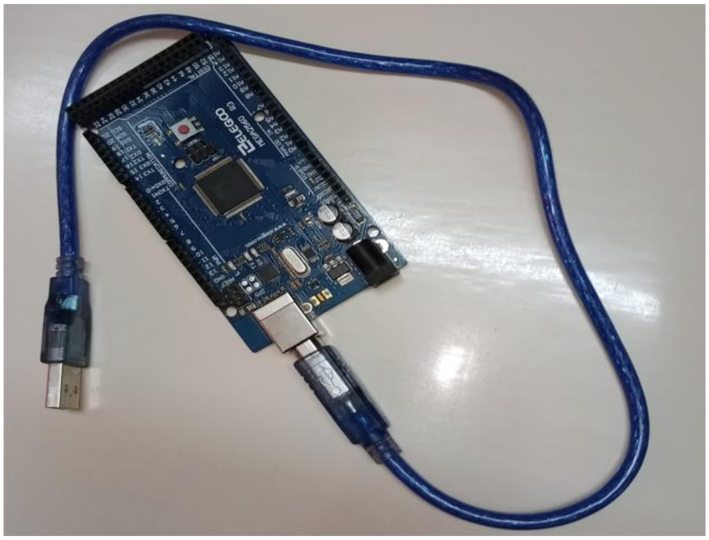

Figure 15: Arduino Mega 2560 Microcontroller.

- **Water Flow Sensor**

Water flow sensors are installed at the water source or pipes to measure the rate of water flow and calculated the amount of water flowed through the pipe. Rate of flow of water is measured as liters per hour or per minute. For our prototype to be as little as possible, the water flow sensor **model: YF-S201** (**Fig. 16**) was used because of its small size: 2.5 " ×1.4 " ×1.4 ".

Figure 16: Water flow sensor model YF-S201.

One can see through the **Fig. 17** the different parts of the **YF-S201** and quickly understand how it works.

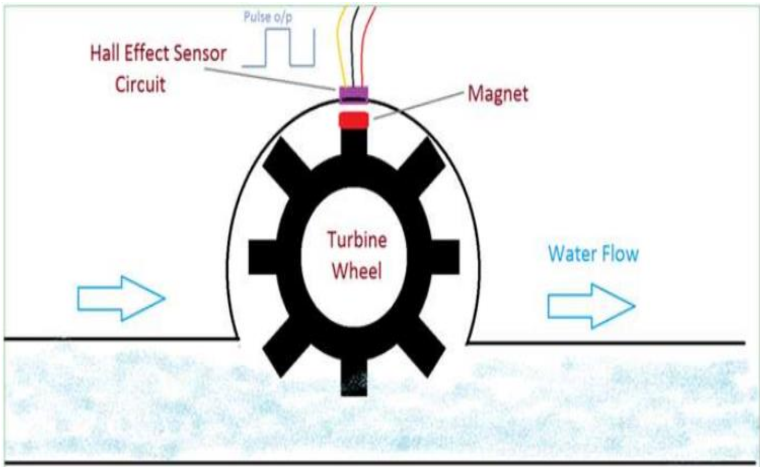

Figure 17: Internal parts of the water flow sensor.

Water Volume Calculation

For every liter of water that flows in the YF-S201, the Hall Sensor outputs 450 pulses. So, each pulse means 1/450-liter water flowing through.

When we take the total volume of liquid flowing through the water flow sensor at a certain time t (unit s) as V_total (unit L), and the total number of pulses detected as N. Then we get:

$$V\_total(L) = N \times 1/450(L) \quad (2.1)$$

Also, the total volume of fluid flowing through the water flow sensor is equal to the water flow rate (Q - unit L/s) multiplied by time t(unit s) .

$$V\_total(L) = Q(L/s) \times t(s) \quad (2.2)$$

So, we get：

$$N \times 1/450 = Q(L/s) \times t(s) \quad (2.3)$$

$$N/t = 450 \times Q(L/s) \quad (2.4)$$

N/t happens to be frequency f, so:

$$f = 450 \times Q(L/s) \quad (2.5)$$

$$Q(L/s) = f/450 \quad (2.6)$$

$$Q(L/min) = f \times 60/450 = f/7.5 \quad (2.7)$$

$$Q(L/hour) = f \times 60 \times 60/450 = f \times 60 /7.5 \quad (2.8)$$

- **Solenoid Valve**

Solenoid valves are control units which, when electrically energized or de-energized, either shut off or allow fluid flow. The actuator takes the form of an electromagnet. When energized, a magnetic field builds up which pulls a plunger or pivoted armature against the action of a spring. However, solenoid valves are energy intensive components requiring input voltages ranging from 12V to 220V for some. For our system to be energy-efficient, a solenoid valve with 12V (Fig. 2.5) input voltage was used.

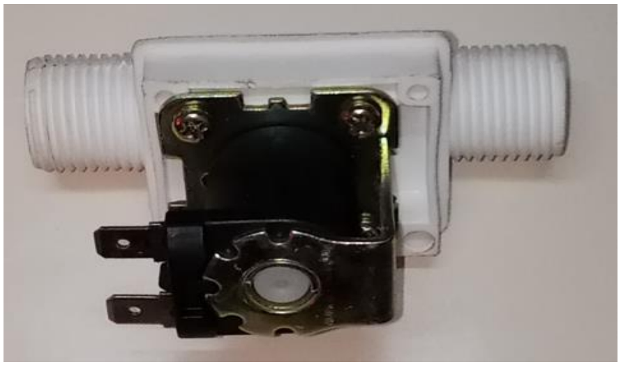

Figure 18: A solenoid valve (12V).

- **Relay Module**

A power relay module is an electrical switch that is operated by an electromagnet. The electromagnet is activated by a separate low-power signal from a microcontroller. When activated, the electromagnet pulls to either open or close an electrical circuit. Here, the relay module (**Fig. 2.6**) was used to control the solenoid valve with the Arduino microcontroller.

Figure 19: Relay Module.

- **Water Turbine Generator**

Water turbine is used to convert energy contained in water, potential energy or kinetic energy, into mechanical or electrical energy. There are two types of water turbine, the reaction water turbine and the impulse water turbine. The latter water turbine (impulse) was used here (**Fig. 20**). Indeed, only kinetic energy of water is used by the impulse turbine. Impulse turbines change the velocity of a high-pressure water jet. Before reaching the turbine blades, nozzles are used to convert the potential energy of high-pressure water into kinetic energy.

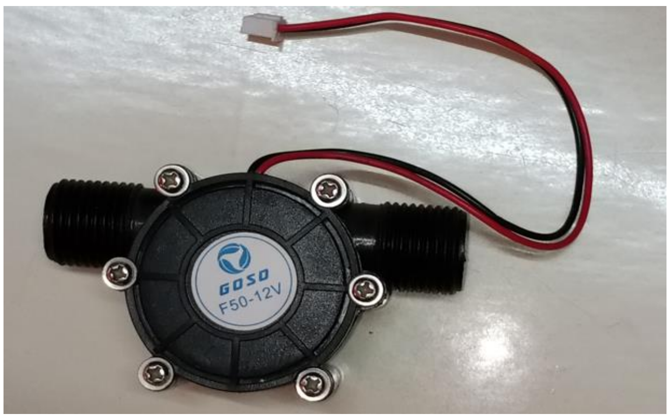

Figure 20: Water turbine generator.

- **GSM/GPRS Module**

Nowadays, Wi-Fi modules such as **ESP8266** or **ESP32 are mostly used t**o send any **sensor data** to the Internet wirelessly. Hence Wi-Fi comes into action and thus **Wi-Fi Connection is needed** for **wireless communication** with any **server**. But the use of Wi-**Fi has some disadvantages as** it is not available everywhere. The Wi-Fi signal is limited to certain locations and to a certain range up to a few meters.

So, **GSM/GPRS** is the only alternative left as per the present scenario and current technology. **GSM/GPRS Module** allows you to add **location-tracking, voice, text, SMS**, and **data** to your application. It was used in our system (**see Fig. 21**) because of its big advantage of **connectivity** as it covers a wide area and signal/connectivity is available almost everywhere. Airtel SIM card was inserted inside it.

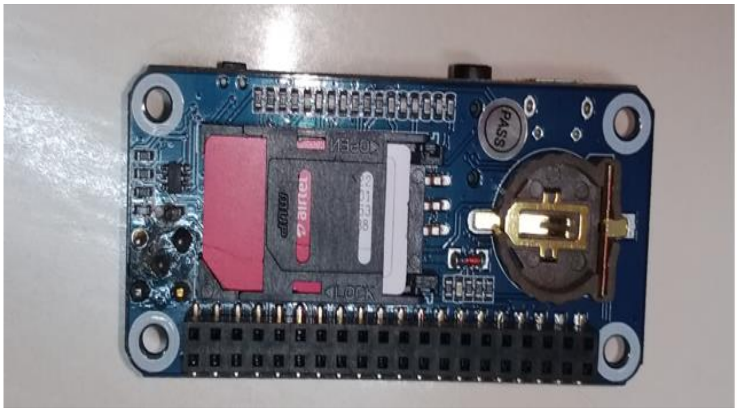

Figure 21: A GSM/GPRS module with Airtel card SIM inserted inside.

- **SD card memory and SD Card Module**

Storing data is one of the most important parts of this research project. There are several ways to store data according to the data type and size. In our system, SD Card memory (4GB) and SD Card Module (see **Fig. 22**) were used for specific data storage.

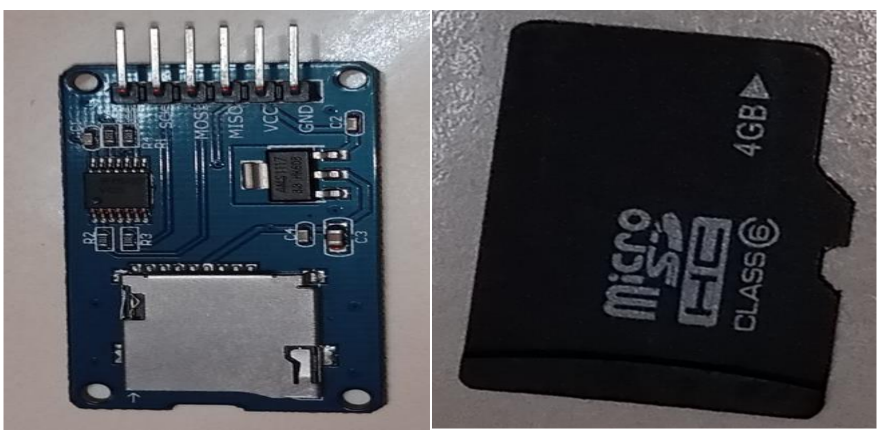

Figure 22: SD card module (left) and SD card memory (right).

- **Keypad**

Keypad is a great way to let users interact with a machine /device. One can use it to navigate menus, enter passwords, control games and robots, etc. A 4×4 matrix membrane keypad (see Fig. 23) was used in our case to allow interaction between a user (example hotel guest) and the system.

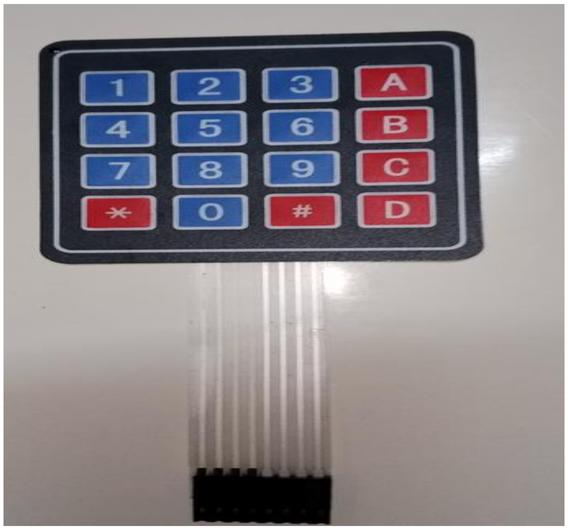

Figure 23: Keypad.

- **Real Time Clock (RTC) Module**

In many systems it is necessary to run an operation according to the time or date and the calculation of the time and date shouldn't stop when the system shuts down. However, there are several ways to get the current date and time. We can get it from an *RTC*, a **Global Positioning Device** (*GPS) device,* or a *time server*. The RTC is a very popular and accurate source of time and date in an embedded system like an Arduino because it has low power consumption. So, to always keep track of current date and time, an **RTC model: DS1302** (**Fig. 24**) was used in our system.

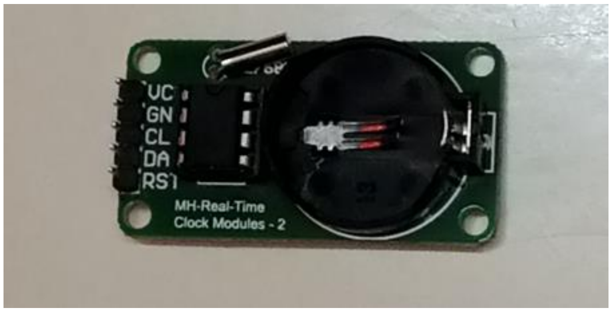

Figure 24: RTC model DS1302 module.

- **Liquid Crystal Display (LCD)**

Display devices are used to visually display the information we are working with. LCD screens are one of the many displays used by device manufacturers. They are very popular and widely used in electronics projects for displaying information. There are two (2) types of LCD: the standard LCDs and the LCDs I2C. However, wiring between Arduino and the standard LCD is complicated. Therefore, LCD I2C has been created to simplify the wiring. Actually, LCD I2C is composed of a standard LCD, an I2C module and a potentiometer. An LCD I2C screen (**fig 25**) was used here because of its simpler connection to the Arduino microcontroller.

Figure 25: LCD I2C screen.

- **Piezoelectric Buzzer**

A piezoelectric buzzer or simply a buzzer is a device that produces sound by adhering a piezo-electric disc to a thin metal plate and then applying electricity. When bending the metal back and forth, noise is created. They are commonly used in alarm clocks and other applications where an audible alarm is needed. It was used in our system to issue a sound warning alert to the user.

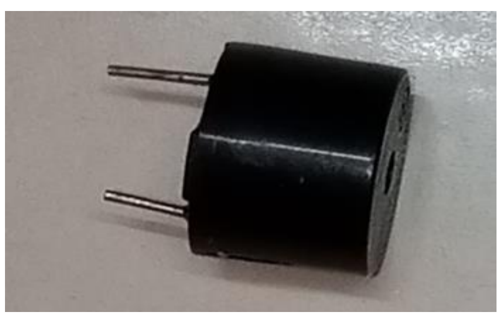

Figure 26: Piezoelectric buzzer.

➢ Light Emitting Diode

A LED in electronics, is a semiconductor device that emits infrared or visible light when charged with an electric current. Visible LEDs are used in many electronic devices as indicator lamps, in automobiles as rear-window and brake lights, and on billboards and signs as alphanumeric displays or even full-color posters. A red LED and a green one were used in our system to also turn on a warning light at a certain time.

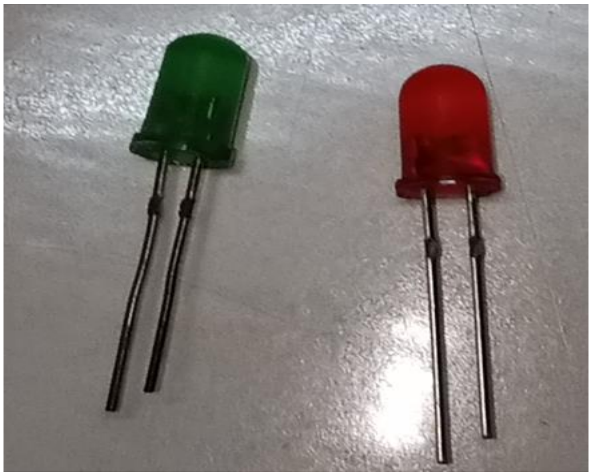

Figure 27: A green and a red LED.

➢ Breadbord

The breadboard is used to make quick electrical connections between the Arduino microcontroller and other sensors by using wire connectors.

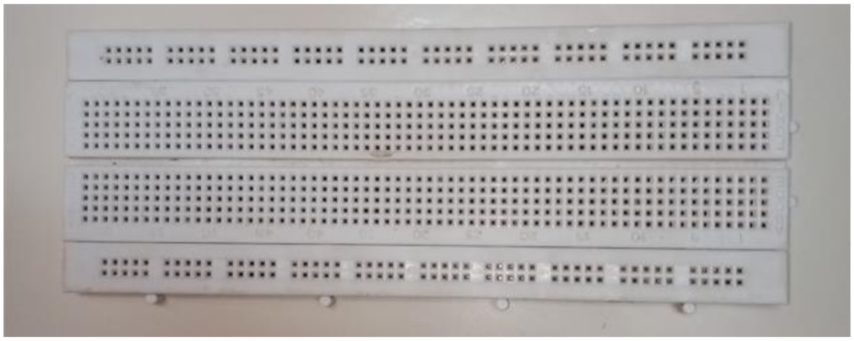

Figure 28: Breadboard.

➢ **Lithium battery**

The figure (2.16) shows a lithium battery 11.1V, 2Ah used to power (22.2 Wh) our smart WSD system.

Figure 29: Lithium battery to power the smart WSD system.

2.4. Methods

To achieve the three (3) specific objectives of this thesis, three (4) mains steps were followed:

i. Data cleaning and processing of the raw data collected during the on-site survey carried out in seventeen (17) hotels in Niamey.
ii. Calculation/estimation of the daily average amount of showering water per guest in Niamey hotels (specific objective 1).
iii. Selection from the general literature review of suitable efficiency requirements that can contribute to reduce shower water waste in hotels. Then, some additional customable efficiency requirements taking into account the local context were proposed in this work. Next, the selected efficiency requirements from literature and those proposed in this work were merged to finally get efficiency requirements that a smart device system should meet to be able to reduce shower water use in Niamey (specific objective 2).
iv. Finally, a user-friendly smart WSD system was developed to manage shower water use in Niamey hotels with respect to efficiency requirements (specific objective 3).

The figure below (Fig. 30) shows in summary the flow chart of the methodology used in this research.

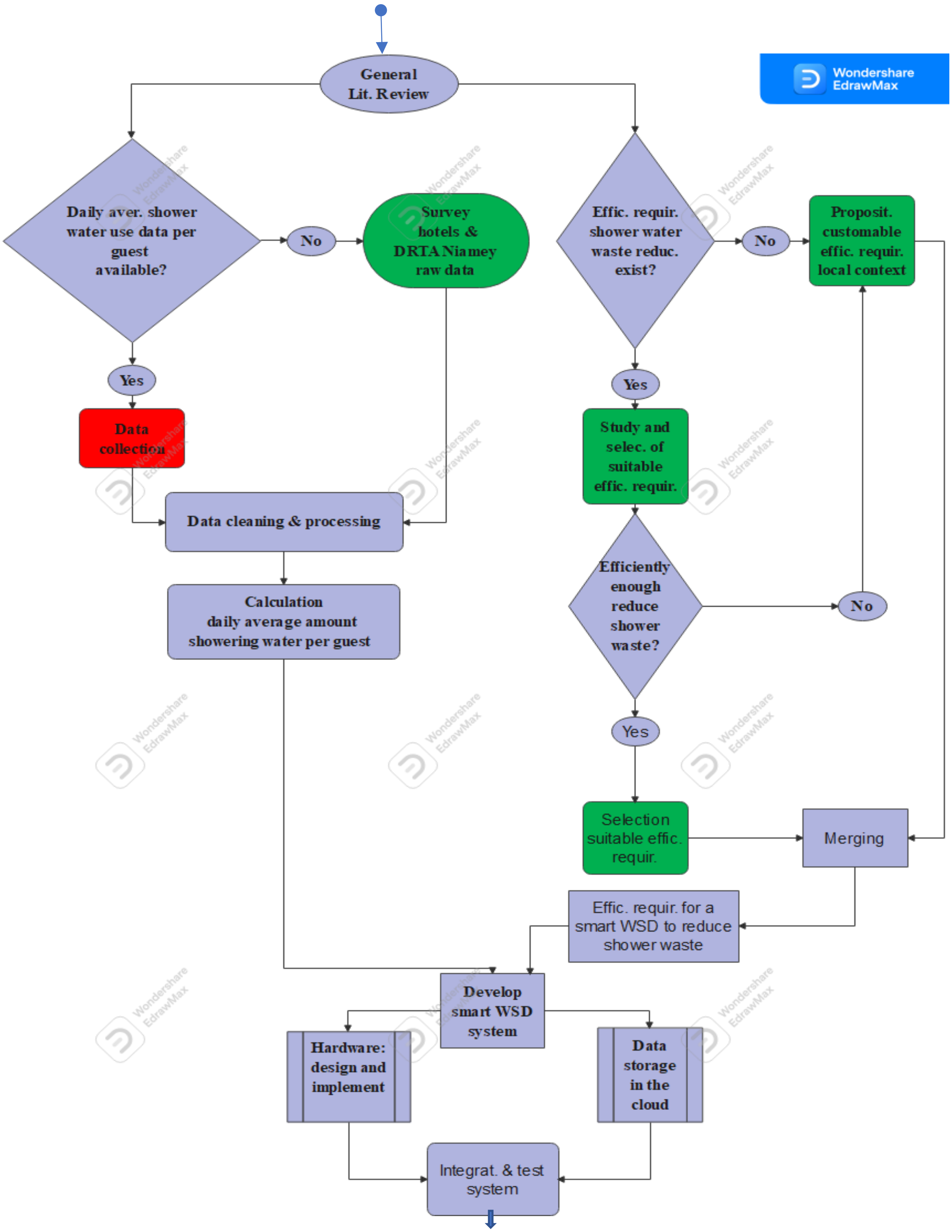

Figure 30: Flow Chart of the Methodology process.

2.4.1 Data cleaning

The data cleaning was done to remove unwanted data from the dataset collected from the survey carried out in Niamey hotels. During this survey, the daily average amount of showering water per guest data were first requested. But, those kinds of data were not available in any hotel where the survey was carried out. Thus, monthly water consumption data and others types of data (occupancy rate, room number, bed number, etc.) necessary to calculate/estimate daily average amount of showering water per guest were collected in those hotels. Indeed, monthly water consumption data from 2019 to 2021 were requested. However, due to the unwillingness of these hotels to provide their data to anyone, only a few months of data for the year 2021 was provided to us, and this, by only 70% of the hotels taken as a sample. Among the 70% of hotels, only one hotel (called Noom Hotel) agreed to provide us with complete data, i.e., monthly data from 2019 to 2021 and even January 2022. The remaining 30% categorically refused to provide us with their data.

After the data cleaning process, the dataset used to calculate the daily average amount of showering water per guest in Niamey hotels is provided in the following table.

Table 3: Highlights survey data after data cleaning process.

Hotel Name	Hotel Class	Number of guest rooms	Number of guest beds	Occupancy rate	Total water consumption per month (m^3)	Shower water consumption rate
Gawey	4*	200	400	95%	Oct 2021: 4047 Nov 2021: 2329 Dec 2021: 3457	35%
Noom	5*	141	150	85%	Oct 2021: 3018 Nov 2021: 3353 Dec 2021: 3048	15%
Grand Hotel	3*	93	110	87%	Oct 2021: 4127 Nov 2021: 5771 Dec 2021: 1943	10%
Terminus	3*	62	124	85%	Oct 2021: 4127 Nov 2021: 5771 Dec 2021: 1943	50%
Sahel	3*	43	70	65%	Oct 2021: 174 Nov 2021: 343 Dec 2021: 306	40%
Oasis	Not classified	30	36	90%	Oct 2021: 149 Nov 2021: 244 Dec 2021: 218	33%
Maourey	Not classified	19	24	60%	Oct 2021: 85 Nov 2021: 78 Dec 2021: 91	31%

2.4.2 Calculation of the daily average amount of showering water per guest in Niamey Hotels

The formula used to calculate the daily average amount of showering water per guest in Niamey is as follow:

- Calculation of the daily average amount of showering water of a hotel ***DAASWH***:

$$DAASWH = \sum_{i=1}^{n} \frac{TWCPMH_i}{92} \quad (2.9)$$

Where:

TWCPMH: Total Water Consumption Per Month of a Hotel,

n=1,…,3 is the number of months, and

92= is the number of days of the three months.

- Calculation of the Average Number of Guest Per Day in a Hotel ***ANGPDH***:

$$ANGPDH = (NGBH \times ORH)/100 \quad \mathbf{(2.10)}$$

Where:

NGBH: is the Number of Guest Beds in a Hotel, and

ORH: is the Occupancy Rate of the Hotel.

- Calculation of the Daily Average Amount of Showering Water Per Guest in a Hotel ***DAASWPGNH***:

$$DAASWPGH = DAASWH / ANGPDH. \quad \mathbf{(2.11)}$$

- Estimation of Daily Average Amount of Showering Water Per Guest in Niamey Hotels ***DAASWPGNH***:

$$DAASWPGNH = \sum_{j=1}^{m} \frac{DAASWPGH_j}{m} \quad (2.12)$$

Where:

m=1, ..,7 is the number of considered hotels in Niamey**.**

2.4.3 Inventory of some efficiency requirements to reduce shower waste

As the freshwater resource is becoming scarce, conservation and good management of fresh water resources have a high priority around the world. Yet, we now have many opportunities to conserve and well manage freshwater resource. One particular opportunity for conservation and good management of water is a better management and reduction of shower water. Many efficiency requirements to reduce shower water waste exist. In this section, an inventory of some of them is provided.

- According to Farmer (2019), one approach to water conservation in a shower is the use of low flow shower-head.
- Showers & Bonjar (2004) studied personal water use habits for domestic uses and found that the water consumption for showering is considerably high compared to other uses. In a survey carried out during the same study, fifty (50) people from different social background were asked why they do not shoot the tab off when the water is not needed during shower taking sessions. The response given by most of those people is as follow: "Closing and opening tab is a boring action and is difficult to repeat several times during a period of 10 or 15 minutes, the average required time for taking a shower". We think that people will still continue doing these kinds of bad habits if their daily amount of shower water is not limited.
- "In 2004, a cluster of relief agencies developed the document entitled *Sphere Humanitarian Charter and Minimum Standards in Disaster Response* which set standards for the minimum level of services people affected by an emergency should receive"(Reed & Reed, 2013).

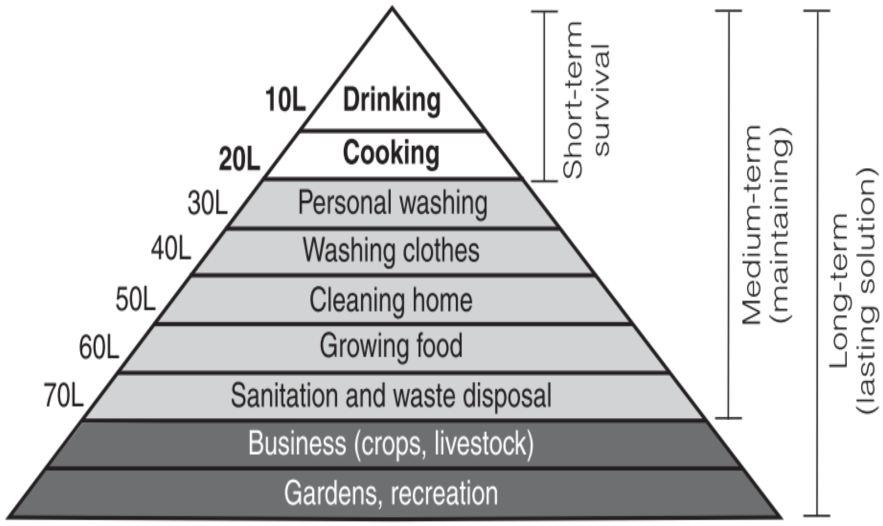

Figure 31: Hierarchy of water requirements.

The above figure (**Fig. 31**) shows that the daily amount of water needed in emergency by a person is 30L.

- One way to conserve water during a shower is to consciously reduce the amount of water by taking shorter shower (Farmer, 2019).
- Water restrictions are very effective in reducing water consumption (Barrett, 2004) and have been in place in Australia for decades. For example, each person has a daily allocation of 140 to 230 liters per person per day (Rachelle, 2011).
- In their work entitled *Incorporating persuasion into a decision support system: the case of the water user classification function,* Perren et al. (2016) stated that: interventions which aim to reduce domestic water consumption differentiate between technological (efficiency) solutions and ***curtailment (limiting water use).*** Thus, Perren et al. (2016) appear to be in favor of limiting the amount of water to be used for certain daily tasks. We believe that the shower should not be an exception.

Therefore, we propose some efficiency requirements that a smart WSD should meet to reduce shower water waste in Niamey:

i. Limit the daily amount of shower water for each hotel guest, but with a possibility to go beyond this limit.
ii. Use a flow meter with a maximum flow rate of 10L/min as the flow meters used in the hotels of Niamey offer an average flow rate of 18L/min (Source: survey carried out in Niamey hotels).
iii. Give an alert to the user when he/she is within 3 liters of the water limit.
iv. Record the delay and the amount of each shower. This would give the user an idea to see how he/she could take a shower without wasting a large amount of water.

2.4.4 Development of a smart WSD system

As the third and last specific objective of this thesis, this section presents the development of a smart WSD system that will user-friendly manage shower water use in Niamey hotels with respect to the efficiency requirements listed above.

2.4.4.1 Design of the hardware part

The design of the hardware part of the system consists of connecting the different electronic components among each other and upload a program that makes the hardware to execute different functionalities.

The connection between different electronic components is as follow:

- The eight (8) pins of the keypad are connected to the pins number 2, 3, 4, 5, 6, 7, 8, and 9 of the Arduino boards.
- The RTC module GND, VCC, Data, Clock and Reset pins are connected to the pins GND, 3.3V, 43, 41 and 45 of the Arduino boards respectively.
- The GND, Transmitter and Receiver pins of the GSM/GPRS module are connected to the pins GND, 11 (Receiver), and 12 (Transmitter) of the Arduino.
- The GND, VCC, MISO, MOSI, CLK, and CS pins are connected to the pins GND, 5V, 50, 51, 52, and 53 of the Arduino respectively.
- The GND, VCC, and the water flow sensor’s main pins to the pins GND, 5V, and 18 of the Arduino respectively.

- The GND and VCC pins of the buzzer are connected to the pins GND and 5V of the Arduino with a 100-ohm resistor placed in series between the VCC of the buzzer and the 5V pin of the Arduino.
- The GND, VCC, and IN+ pins of the relay module are connected to the pins GND, 5V, and 13 of the Arduino respectively.
- The NO and COM pins of the relay module are connected the negative pole of the battery (12V) and to one pole of the solenoid valve.
- The other pole of the solenoid valve is connected to the positive pole of the battery.
- The GND and VCC pins of the GREEN LED are connected to the pins GND and 46 of the Arduino with a 100-ohm resistor placed in series between the VCC of the GREEN LED and the pin 46 of the Arduino respectively.
- The GND and VCC pins of the RED LED are connected to the pins GND and 48 of the Arduino with a 100-ohm resistor placed in series between the VCC of the RED LED and the pin 48 of the Arduino respectively.
- A 12V input and 5V output step-down unit is placed between the battery (12V) and the GSM/GPRS module which needs 5V and 2A to be powered.

After the connection between different elements listed above was completed (**Fig. 32**), the Arduino program was implemented and uploaded to the Arduino Microcontroller.

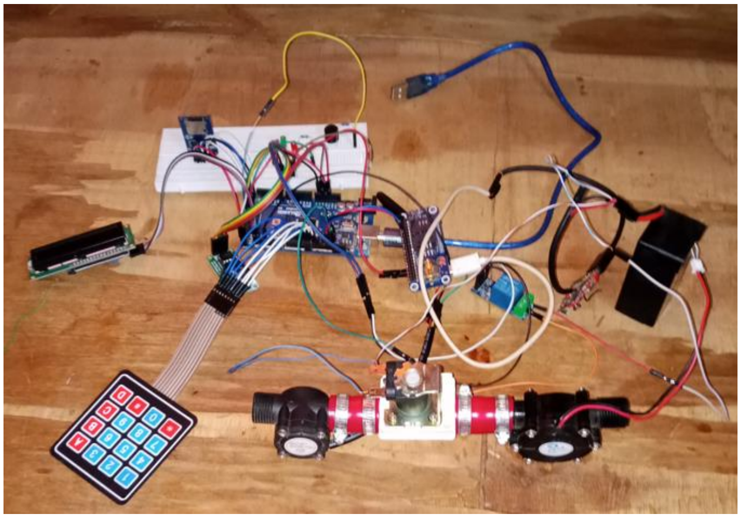

Figure 32: Connection between different elements of the system.

2.4.4.2 Use of Internet of Things (IoT)for data sending to the cloud

IoT is an emerging field of technology where devices or objects have the ability to connect and transfer data over a network without human intervention. These objects or things have sensing capabilities, and they have unique identifiers for addressing and communication. To transfer data from the devices over the internet, cloud computing provides the infrastructure for that data to travel to its destination. Over the years, vendors have created many connected devices, and in the same vein, a lot of IoT cloud platforms have been developed. Examples of IoT cloud platforms include:

- ThingsBoard (https://thingsboard.io/)
- ThingWorx (https://www.4cadgroup.com/fr/ptc-thingworx)
- IBM Watson IoT (https://www.ibm.com/cloud/internet-of-things)
- Node-RED (https://nodered.org/)
- Thinger (https://thinger.io/)
- Sparkfun (https://www.sparkfun.com/)
- ThingSpeak (https://thingspeak.com/)

ThingSpeak was released to the market by ioBridge, and it now has support from MATLAB, thus, giving user access to advanced data analytics tools.

For the designed smart WSD system to send data to the cloud, ThingSpeak platform was chosen.

The reason of choosing ThingSpeak is because it offers multiple advantages:

- ✓ ThingSpeak allows registered users to collect, display, analyze, make inferences, and act on the data;
- ✓ It allows the user to process his data. That is to integrate, convert, calculate new data, and develop IoT applications.
- ✓ Further tools enable data interchange between ThingSpeak and web apps or social media platforms.
- ✓ Users can visualize their sensor data using MATLAB's several built-in plots or display data in gauges, charts, or custom plots.

So, to send the data to ThingSpeak, first of all, a private channel named ThesisData was created. This channel has the following characteristics:

This channel has the following characteristics:

- ❖ **ID**: *********

- **Author**: ************
- **Access**: Private
- **Fields**: HotelName, City, RoomNumber, ShowerCode, Date, ShowerTime, ShowerWaterUsed, and MaxDailyWaterQuanity.
- **Write API Key**: ***********
- **Read API Keys:** ***********
- **API Requests**:
  - Write a Channel Feed:

    GET https://api.thingspeak.com/update?api_key=***********

  - Read a Channel Feed:
    GET
    https://api.thingspeak.com/channels/1784411/feeds.json?api_key=***********

  - Read a Channel Field:
    GET
    https://api.thingspeak.com/channels/1784411/fields/1.json?api_key=***********

  - Read a Channel Status Updated:
    GET
    https://api.thingspeak.com/channels/1784411/status.json?api_key=***********

The term API stands for "Application Programming Interface." Here, API keys enable one to write data to a channel or read data from a private channel. API keys are auto-generated when a new channel is created.

2.4.5 Description of operating principle of the smart WSD system

To well describe the operating principle of the smart WSD system, a sequence diagram (**Fig. 33**) was developed using Unified Modeling Language (UML). UML is a standardized modeling language consisting of an integrated set of diagrams, developed to help system and software developers in specifying, visualizing, constructing, and documenting the artifacts of software systems, as well as in business modeling and other non-software systems.

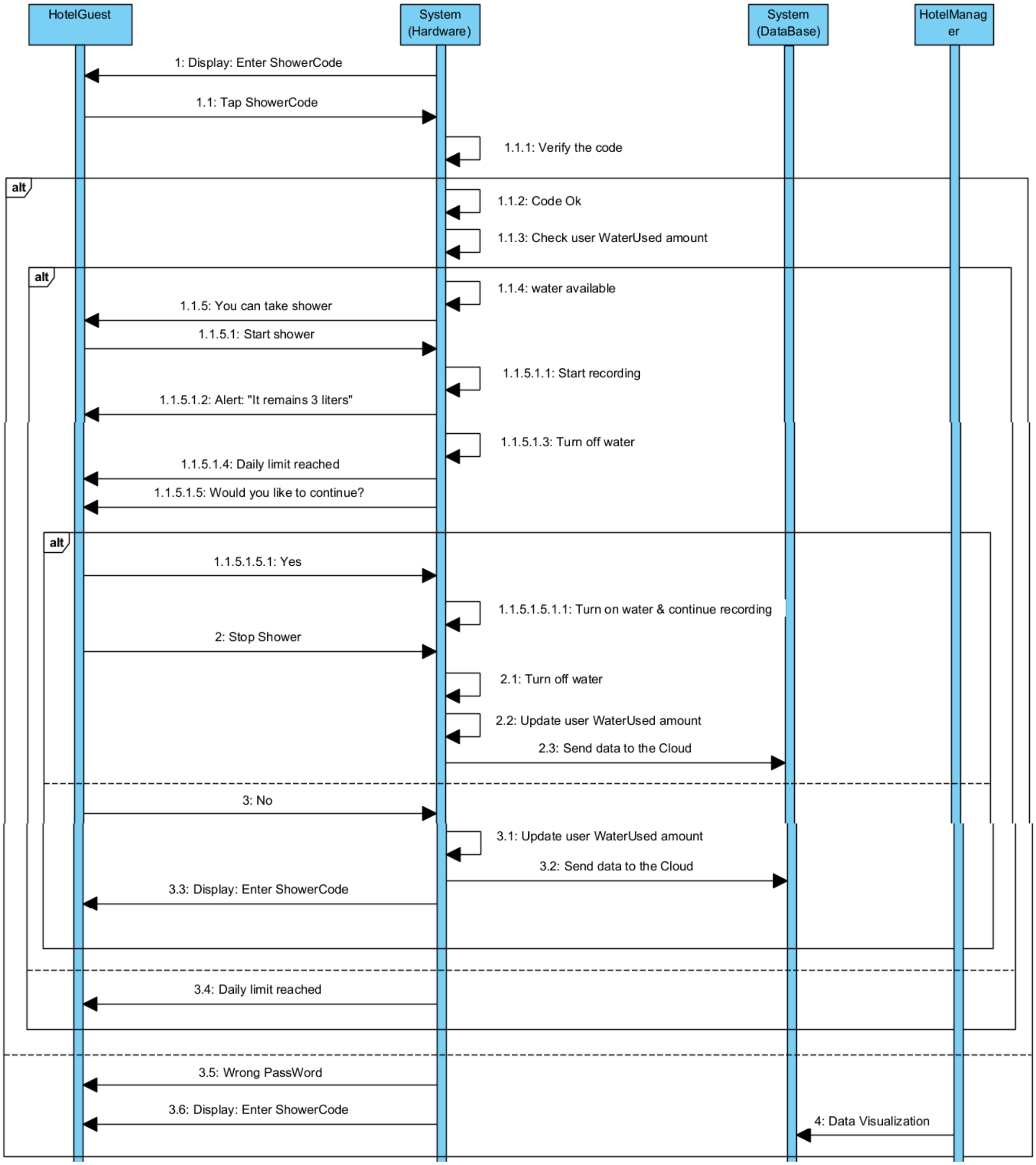

Figure 33: Description of the operation principle of the smart WSD system.

CHAPTER3: RESULTS AND DISCUSSION

This section presents the main findings of this Thesis. First of all, the survey results are presented followed with the estimated daily average amount of showering water per guest in Niamey hotels. Next, the proposed efficiency requirements are evaluated. Finally, the discussion section focuses on the evaluation of the user-friendly smart WSD system developed to manage shower water use in Niamey hotels with respect to those efficiency requirements.

3.1 Results

3.1.1 Survey Results

Two (2) on-site surveys were carried out for the purpose of this work. From the first one carried out at the DRTA of Niamey findings are shown in the table below:

Table 4: Data collected from on-site survey at DRTA of Niamey.

Year	Number of hotels in Niamey	Number of guest rooms in Niamey Hotels	Number of guest beds in Niamey hotels
2019	73	4293	4768
2020	73	4293	4768

Table 4 highlights the data collected at DRTA of Niamey. We can see that the number of hotels, the number of guest rooms, and the number of guest beds in Niamey for the years 2019 and 2020 are the same and correspond to 69, 2048, and 25558 respectively. The non-evolution of hotels number in Niamey in 2020 is due to the impact of COVID-2019. Some of these hotels were even closed due to the lack of guests. The data for the year 2021 were not yet available when this survey was carried out (End January 2022).

The second survey was done to collect the data sample from seventeen (17) hotels in Niamey, Niger. Among the seventeen (17) hotels, only 10 accepted to give their data. These 10 hotels collectively account for 684 hotels guest rooms and 1041 hotels guest beds, which represent 14,50%, 33,40% and 40,70% of the total number of hotels, guest rooms, and guest beds available in Niamey, Niger. The sample of the hotels surveyed comprised three (3) different classes: (i) hotels high class (4 and 5 stars) with number of rooms more than 100, (ii) hotels middle class (2 and 3 stars) with number of rooms greater than 40 and less than one 100, and (iii) hotels low class (not classified and 1 star) with room numbers comprised between 20 and 40. Ten (10) questions were asked in every hotel of the sample. A part of the five (5) types of data obtained (see Chapter 2, Table 2.1), five (5) other questions have been asked (see Chapter 2, section 2.2). As findings from these questions, it appears that none of the hotels in the survey sample:

i. Is a green certified one;
ii. Has installed any type of WSD in the showers of guest rooms;
iii. Has applied any efficiency requirements to reduce shower water waste; and
iv. Is able to monitor/control the daily shower water consumption of guest rooms.

It was in only one hotel (Hotel Gawey) that the technical director explained that since the creation of the hotel in the 70's, they made a study which consists in evaluating the daily water consumption per customer for tasks such as: shower, toilet and ablutions. The estimated amount of water was 70L. He also explained that unfortunately until now, they have no means or technology to limit the daily water consumption per guest in their hotel. He also immediately appreciated and encouraged the objective of this work. For the factors/parameters that can lead to excessive water consumption by clients in the showers, the answers were almost the same in all hotels. There are factors such as: the hot period in Niamey (the months of March-April-May), the use of a flow meter with a very high flow rate of about 18L/min, but also and especially the occupancy rate. They believe that the occupancy rate is the factor that contributes most to the waste of water in the showers by customers. However, the occupancy rate is very high in hotels in Niamey during the winter (November to February).

3.1.2 Estimation of the daily average amount of showering water per guest in Niamey hotels.

The method used to estimate the daily average amount of showering water per guest in Niamey hotels was formulated in Chapter 2, section 2.3.2. Thus, the daily average amount of shower water per guest at each hotel in the sample was first estimated. Then, the daily average amount of showering water per guest in Niamey hotels was estimated by calculating the average of all the hotels in the sample as shown below:

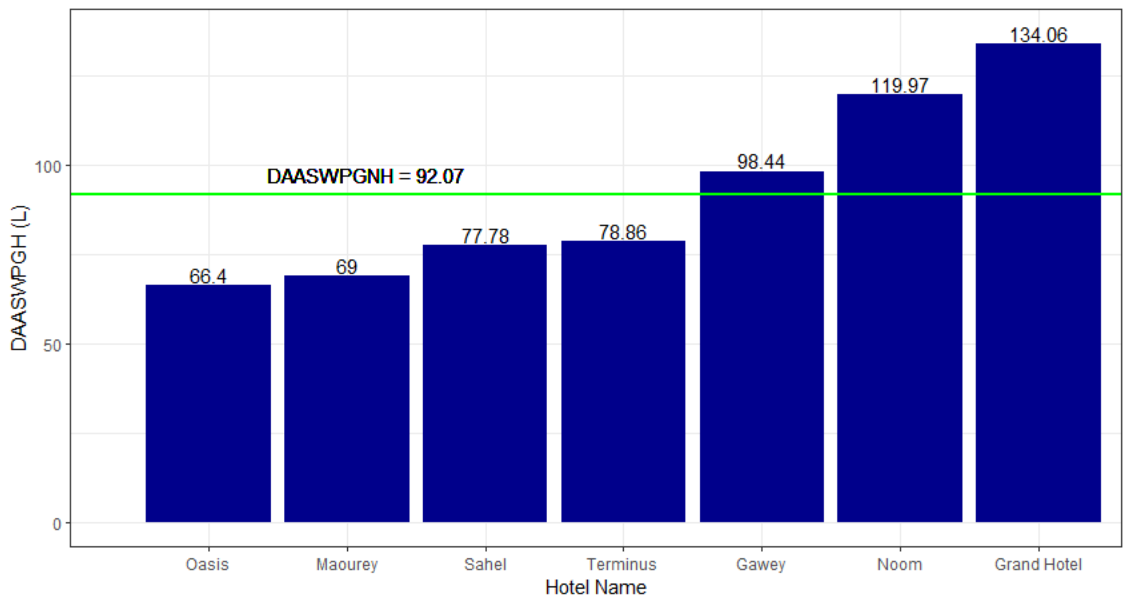

Figure 34: shows the DAASWGH and the DAASWPGNH (L).

By analyzing the **Fig. 34**, one can see that the hotels high class: Gawey (4 stars) and Noom (5 stars) are those in which the daily average amount of shower water per guest is higher than the average (92.07L) with 98.44L and 119.97L respectively. A hotel middle class, Grand hotel has the highest value of daily average amount of shower water per guest with 134.06L. However, hotels low class such as Oasis, Maourey, Sahel, and Terminus are those with daily average amount of shower water per guest lower than the average with 66.4L, 69L, 77.78L, and 78.86L respectively.

3.1.3 Proposition of the efficiency requirements to reduce shower water waste in Niamey

- ✓ In 2019, Niamey alone had a capacity of 4,768 beds in its hotels, which corresponds to about 53.65% of the national capacity of hotels in Niger ("INS Niger," 2020).
- ✓ Given the average daily amount of shower water per client in the hotels of Niamey which is estimated at ***92.07L***, therefore ***very high***.
- ✓ Given the large capacity of hotels in Niamey on a national scale, therefore a large amount of water consumption in the showers of hotels in Niamey.

- ✓ Given the great diversity of the hotels considered in this work, high class hotels, medium class hotels and low-class hotels.

We propose to:

- Limit the daily amount of shower water per guest to **50L** in hotels in Niamey, but with the possibility of exceeding this limit.
- Use a flow meter with a maximum flow rate of 10L/min instead of the flow meter used in Niamey hotel showers, which offer a flow rate of up to 18L/min (Source: survey conducted in Niamey hotels).
- Give an alert to the user when 3L of water remains in the daily shower water consumption limit.
- Record the duration and amount of water per shower a guest takes. This will allow each hotel to have full control over the shower water consumption of their guests.

3.1.4 Development and testing of the smart WSD system

3.1.4.1 Development

The prototype of the smart WSD system consists of an Arduino Mega 2560 microcontroller, a water flow sensor, a solenoid valve, a relay module, a water turbine generator, a GSM/GPRS module, an SD card module, an SD card memory (4GB), a keypad, an RTC module, an LCD I2C screen, a piezoelectric buzzer, a green and red LEDs, and a breadboard.

Indeed, the smart WSD system was developed to execute a lot of tasks such as:

- ❖ Measuring a hotel guest's shower water consumption. Thus, the water flow sensor is used to measure the shower water volume. But, before even its insertion in the system, the water flow sensor (model: YF-S201) was first tested by implementing an Arduino code which was also uploaded to the Arduino microcontroller. The obtained results are given in (see **Fig. 36** filed6 and filed7 corresponding to the delay and the amount of shower water used respectively). It should also be noted that the water flow sensor used has a maximum flow rate of 10L/min, thus allowing an efficient use of water rather than wasting it.

- ❖ Being a self-powered device. However, when the water passes through the water turbine generator (Model: GOSO F-50 12V), it will generate a voltage of 12V which will charge the internal lithium battery. This battery is used to supply power to the whole system. So, the smart WSD doesn't need any external power supply.
- ❖ Ensuring the management of the daily shower water consumption of the customers. Since the guest rooms in Niamey hotels have a maximum number of two beds, the intelligent WSD has an internal storage memory in which four user codes and their daily water quantities are stored. Each time a client uses his code to shower, the system will automatically remember his last consumption. Also, each day when it is 00:00, the intelligent WSD will automatically reset the daily amount for each user to zero for the new day that starts.
- ❖ Ensuring data sending in the cloud (online database). Every time a customer finishes showering, the intelligent WSD will automatically send some data to the cloud i.e., the online database (ThingSpeak) through the GSM/GPRS module. Eight (8) types of data are sent namely hotel name, hotel city, guest room number, guest shower code, date, duration of shower, amount of water used by guest and maximum daily amount of water used by guest.

Finally, the smart WSD system is very user-friendly because it guides the user during its use. Indeed, when the user is at a step i, the smart WSD will show him the step i+1. For example, when the customer is showering, in addition to showing him his current water consumption, it will tell him which button to press in case he wants to stop the water for a few moments to lather up for example, or to completely stop his shower.

3.1.4.2 Testing

The prototype of the smart WSD system was tested during three (3) days but not in a shower. The test was conducted by connecting the device to a tap from the 1st to the 3rd of July 2022. The smart WSD system worked very well for each user. Indeed, each of the four (4) users' passwords were used once a day to do a test just for a short time (not more than four (4) minutes. The **fig. 35** shows the data sent to the ThinkSpeak database.

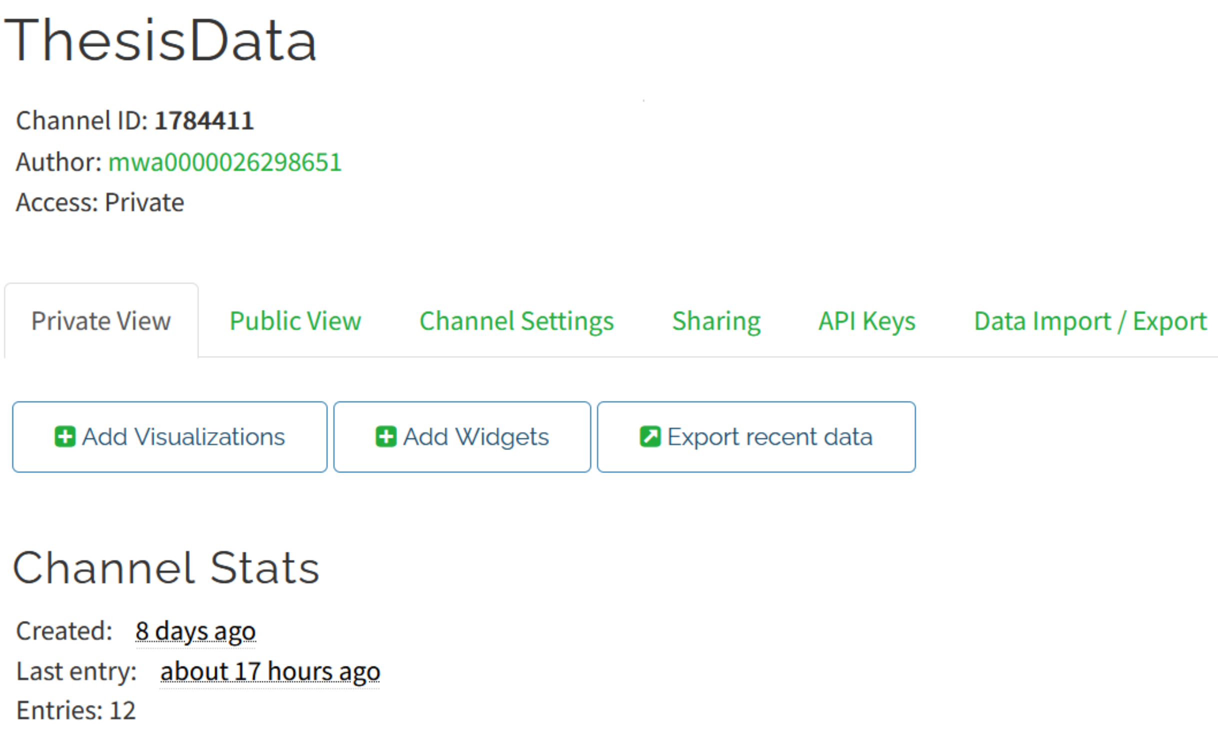

Figure 35: Data sent to ThinkSpeak online database.

One can see through the above figure **(Fig. 35)** the data sent by our smart WSD system. As four (4) users were used to do the test once per day during three (3) days, we have a total number of 12 data sent to ThinkSpeak database as shown in the Fig. 35.

In addition, these data could be exported as JSON, XML, and CSV files.

After a test of each user, 8 types of data are sent to the ThingSpeak database named ThesisData. These 8 data are hotel name, city (where the hotel is), room number (where the hotel guest is supposed to be using the smart WSD), shower code (appropriate to the guest to take a shower), Date (he/she took the shower) , shower time (the delay of the shower), shower water used (the amount of water consumed during the shower), and the maximum daily water quantity (is equal to 50L per day). The data are stored in field1, field2, field3, field4, field5, field6, field7, and field8. The smart WSD is supposed to be tested in hotel Noom of Niamey in the room number 105. **Fig. 36** shows the data exported as XML files.

A	B	C	D	E	F	G	H	I	J
created_a	entry_id	field1	field2	field3	field4	field5	field6	field7	field8
2022-07-0	1	Noom	Niamey	105	1111	1/7/2022	2.6	10.3	50
2022-07-0	2	Noom	Niamey	105	2222	1/7/2022	3.4	12.25	50
2022-07-0	3	Noom	Niamey	105	3333	1/7/2022	3.12	9.97	50
2022-07-0	4	Noom	Niamey	105	4444	1/7/2022	2.6	5.84	50
2022-07-0	5	Noom	Niamey	105	1111	2/7/2022	2.35	7.14	50
2022-07-0	6	Noom	Niamey	105	2222	2/7/2022	2.72	8.23	50
2022-07-0	7	Noom	Niamey	105	3333	2/7/2022	2.48	7.35	50
2022-07-0	8	Noom	Niamey	105	4444	2/7/2022	3.5	15.55	50
2022-07-0	9	Noom	Niamey	105	4444	3/7/2022	3.2	13.17	50
2022-07-0	10	Noom	Niamey	105	1111	3/7/2022	2.75	8.87	50
2022-07-0	11	Noom	Niamey	105	3333	3/7/2022	1.85	5.2	50
2022-07-0	12	Noom	Niamey	105	2222	3/7/2022	3.85	15.6	50

Figure 36: screehshot of data exported as XML file from thingSpeak.

3.1.4.3 Estimating the efficiency of the smart WSD system

To estimate the efficiency of the smart WSD system after its implementation, we made three (3) assumptions:

1. In 2020, the total number of guest rooms in Niamey hotels was 4293.
2. The estimated daily average amount of showering water per guest in Niamey hotels is 92,07L.
3. From the survey data, the estimated average occupancy rate of Niamey hotels is 61,5%.

Based on the assumptions made, the **table 5** below shows the daily, monthly, and annually amount of shower water consumption in Niamey hotels when each of the following scenarios is considered:

(a): the smart WSD system is not installed and the daily average amount of showering water per guest is equal to 92.07**.**

(b: the smart WSD system is installed in every hotel guest room of Niamey and each guest in Niamey hotels decides to respect the limit of the daily amount of shower water per guest which is **50L.**

(c) the smart WSD system is installed in every hotel guest room of Niamey and some hotel guests decide to consume beyond the limit of their daily amount of shower water.

Table 5: Shower water consumption in Niamey hotels based on the assumptions and scenarios made.

Period	**Water consumption (m^3) when 1, 2, 3, & (a)**	**Water consumption (m^3) when 1, 2, 3, & (b)**	**The Gain (a) – (b)**	**Water consumption (m^3) when 1, 2, 3, & (c)**
Daily	269,97	146,616	123.354 (45.70%)	146.616 + X
Monthly	8099,36	4398,48	3700.88 (45.70%)	4398.48 + Y
Annually	98542	53514,84	45027.16 (45.70%)	53514.84 + Z

The **table 5** quickly shows that if the three (3) assumptions made and the scenario **(b)** are considered**,** about 45027.16 m^3 (45027160 L) amount of water will be saved annually which is equivalent to 45,70% of the amount of water consumed when **(a)**.

Furthermore, if we keep the three (3) assumptions and the scenario **(c)**, we will still have saved water depending on the number of hotel guests who will continue to be faithful to the respect of their limit of daily amount of shower water. In that case, this work would try to recommend to different hotels see how they can add an additional charge on guests who use more than their limit. On the other hand, hotels should contribute to the protection of the environment by funding national and international organizations in charge of environmental protection.

3.2 Discussion

Hawrylak et al. (2015) implemented a WSD called **HydroSense** in the U.S**.** According to them, hotels significantly contribute to increased water consumption in the U.S. and around the world. This is due to the fact that most hotels are not able to monitor shower water use in guest rooms. Thus, **HydroSense**, a novel low cost, accurate, small size, low power, wireless device was designed for monitoring water use from hotel room showers in the U.S. Its target is to promote water conservation among hotel guests. But in reality, **HydroSense** was designed for the purpose of improving hotel's revenue in the U.S, i.e, hotel guests who use a large amount of water for showering will be charged for excessive water use. Anyway, HydroSense is a good WSD because the hotels where it is installed to monitor the water consumption of guests' showers have decided to fund local institutions in charge of environmental protection.

Alegre et al. (2017) in their study intitled "*Assessment of water-saving equipment to support the urban management of water"*, have analyzed the environmental and economic impacts of the implementation of water-saving equipment in residences in the municipality of Caruaru-PE. Since 2012, the Northeast of Brazil is suffering a severe drought, regarded as the longest over the past 50 years, according to Abicalil (2014); as a consequence, many of the reservoirs that supply the municipalities are collapsing, which means it no longer offers the conditions for capturing water for human consumption. So, Alegre et al. (2017) have carried out this work in order to contribute to finding a solution to the water problem faced by the Northeast of Brazil. After the study, results demonstrated that it is possible to save up to **40% of consumed water only with the implementation of water-saving equipment**, with a mean return time of six and a half years. Therefore, it is possible to understand that the use of water-saving equipment represents an important instrument of water management.

To the best of our knowledge there is still no study related to the implementation of WSDs in order to contribute to water conservation before, in the whole of West Africa. Niger is no exception.

However, the proposed smart WSD system was developed to reduce shower water waste in Niamey hotels. After testing the smart WSD and based on some assumptions made, the results show that a significant amount of water could be saved in Niamey hotels. Indeed, about 45,70% of consumed shower water could be saved.

CONCLUSION AND PERSPECTIVES

This research can be considered as a first step for the development of ESTs in West Africa. It investigated the potential use of a smart WSD system for water conservation in showers of Niamey hotel guest rooms. WSDs are well known as examples of ESTs used for good water management and wasted water reduction in domestic, agricultural, and industrial sectors. This work proposed to evaluate the efficiency of our smart WSD system when it's implemented in Niamey hotels. Therefore, this work confirms that the developed smart WSD system efficiently contributes to significant water conservation in Niamey hotels based on some assumptions made. Indeed, the main findings of this research are:

- ✓ The estimated daily average amount of shower water (L) per guest in all Niamey hotels is:
    - DAASWPGNH = 92.07.
- ✓ A proposition of some efficiency requirements to reduce shower water waste in Niamey hotels was done. These efficiency requirements are:
    - Limiting the daily amount of shower water per guest to **50L** in hotels in Niamey, but with the possibility of exceeding this limit.
    - Using a flow meter with a maximum flow rate of 10L/min instead of the flow meter used in Niamey hotel showers, which offer a flow rate of up to 18L/min (Source: survey conducted in Niamey hotels).
    - Giving an alert to the user when 3L of water remains in the daily shower water consumption limit.
    - Recording the duration and the amount of shower water each guest takes. This will allow each hotel to have full control over the shower water consumption of their guests.

- ✓ The smart WSD system efficiently contributes to a significant water conservation in Niamey hotels. When implemented, about 45,70% of consumed shower water could be saved in Niamey hotels.

The verification of the hypotheses of this research is as follows:

i. The daily average amount of showering water per guest in Niamey hotels was estimated. But it would be interesting to increase the number of representative hotels where the on-site survey was conducted, to achieve around 25% of the total number of hotels in Niamey.

ii. The proposition of some efficiency requirements to reduce shower water waste in Niamey hotels was done.

iii. A user-friendly smart WSD system to manage shower water use in Niamey hotels with respect to the proposed efficiency requirements was developed.

The prototype of the smart WSD system developed in this work is not a finished product that is ready to be used for months or even years in a shower. Therefore, it needs:

- Be Printed Circuit Board (PCB) assembly. A PCB assembly describes the finished board after all the components have been soldered and installed on a PCB.
- A 3D printing in order to be put in a box as a finished product.
- Finally, a local database creation to which the smart WSD system will send the data will be very important especially for data security.

However, apart from hotel showers, smart WSD could be implemented in all places where water is used in a non-moderate way such as university campuses, residences, and even in the domestic sector in order to check who among family members are those who waste too much water

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