Is non-conventional low cost weather station a sustainable monitoring system?

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Abstract

Today massive sets of digital data are produced by computers using internet (IOT). This development has impacted on climate monitoring systems and therefore a large set of environmental real-time data can be generated from modern smart devices. In parallel to this development, open weather monitoring systems have been introduced to observe the weather data and analyse climatic conditions. In Sri Lanka, considering climate data, rainfall, humidity, temperature and wind speed are measured primarily manually. Further, focusing on climate data (which in a broad sense include meteorology, oceanography and climatology information), the country does not have a well-connected weather observing networks that routinely provide data of the necessary quality and spatial and temporal density. Similar to other developing countries, Sri Lankan weather monitoring system is not real-time and/or are not dense enough to monitor local conditions that can evolve rapidly. This situation has existed due to limited budgets, lack of technical infrastructure and associated expertise, rapid deterioration, lack of skilled maintenance, high-priced non-locally available spare parts. In recent years, Sri Lanka has experienced a fast growth in mobile connectivity and smart device and this development is certainly a positive opportunity for setting-up monitoring systems at low-cost which could be used to address a number of practical issues including, but not limited to, floods, climate change, risk management and weather predictions. In this study, we intend to design and test an open non-conventional climate weather monitoring station named 4ONSE weather station. This is 4times open: Open Hardware, Open Software, Open Standards and Open Data. "Non-conventional" means we intend a low-cost system which doesn't respects all the high standard requirements in term of sensor construction, precision and testing and, finally, for "effective way" we intend to meet the users' needs. Even though Open weather stations of this nature have been installed elsewhere, little research has paid attention to investigate the sustainability aspects of such systems. In this research paper, we attempt to explore cost, conformity with WMO standards and system design to cope with tropical climatic condition of the country. By doing that we argue that whether 4ONSE weather station is a sustainable climate monitoring system or not.

Keywords: 4ONSE, weather station, open source hardware, open source software, Deduru Oya basin

1. Introduction

Novel technologies and concepts, including the Internet of Things (IoT) enable the production of massive amounts of digital data. These emerging technologies and concepts, mainly in the fields of Computer Science and Information and Communications Technology (ICT) have made it possible to operate more effectively toward environmental monitoring and disaster risk reduction (DRR) (Cannata et al., 2016). The IoT based applications have started to become popular as more cost-effective products due to integration of open hardware, open software and open standards in the system design and development. Costs of environmental monitoring is being reduced by utilizing open source software packages and open source hardware sensors in modern Environmental Monitoring Systems (EMS) (Cannata et al., 2016). With regards to monitoring and analyzing environmental conditions in Sri Lanka, absence of a well-connected environmental monitoring network that routinely provides precise real-time data has been a major bottleneck for decades. As a result of this, data such as rainfall, relative humidity, air temperature, light intensity and wind speed are measured fundamentally manually. This situation has existed mainly due to limited budgets, absence of technical infrastructure and associated expertise, shortage of skilled maintenance and inability to afford internationally available weather instruments and equipment due to the high costs.

In order to make best use of the existing resources and technical expertise, it was intended to design, develop and test a 'four times open i.e. using open hardware, open software, open standards and open data and non-conventional environmental monitoring station named the 4ONSE (4 times Open & Non-conventional technologies for Sensing the Environment). This research project is being jointly carried out by the University of Moratuwa, Sri Lanka and University of Applied Sciences and Arts of Southern Switzerland and was initiated in a time where the necessity of a low-cost, non-conventional and precise hydro-meteorological monitoring system has been of great demand due to the increased number of weather-related environmental hazards and disasters that have been taking place in the island. Despite the fact that open source weather monitoring systems that are quite affordable have become popular worldwide, the level of sustainability of such systems has only been paid a little attention in the field of research. This work comprises an attempt to exploring the level sustainability of the 4ONSE weather monitoring system with regard to its cost, maintenance and quality of data.

2. Literature Review

Meteorological towers known as met towers are the foundation of environmental or atmospheric measurements of the surface. These towers are typically constructed of steel tubing and are permanently fixed to the ground which consumes significant hours of labour and support equipment when constructing and transporting them, especially if the deployment location is in a remote area (Gunawardena et al., 2018). In addition to this practical drawback, these large, heavily-instrumented met towers are of high cost which makes it difficult for researchers to deploy more than a few. Consequently, the spatial coverage of these would be limited, resulting in not being able to accurately measure the complex terrain that has high spatial heterogeneity (Gunawardena et al., 2018). According to Gunawardena et al. (2018) in their study, all aforesaid limitations of traditional met towers could finally lead to them having destructive consequences to experiments and research. The reason behind is that the deployment of such met towers in small numbers have no redundancy, thus equipment failures would certainly obstruct the experiments being carried out.

An alternative to such conventional large met towers as suggested by Akyildiz et al. (2002), was the use of large numbers of small, distributed sensor stations which are self-contained and could be carried by an individual. Such distributed sensor stations would cost anywhere from tens to thousands of dollars which is comparatively less expensive than a met tower. This cost includes all instruments, housing, data logger and power system that is typically batteries or solar (Akyildiz et al., 2002). An example of a common distributed sensor station given by Gunawardena et al. (2018) was the Onset HOBO U23 Pro v2.

Among the advantages of these distributed sensors are that they could be deployed in a wider variety of environments due to their small, easy-to-carry size; their lower costs enable researchers to deploy as many stations as required, increasing spatial coverage and resolution and they are quite immune to data loss when compared to traditional met towers as replacing sensors is a minor task due to the low-cost (Nelson et al., 2007). Distributed sensor systems are being used in many different fields and several applications, including wildlife habitat monitoring, forest fire detection, military purposes, health sector, home related applications and climate and environmental monitoring.

Nevertheless, one of the major technical problems that could occur in distributed sensor systems is the power consumption i.e. the usage of smaller and cheaper batteries for these low-cost smaller stations may lead to reducing the available power to run the system (Yick, Mukherjee and Ghosal, 2008; Anastasi et al, 2009; Rault, Bouabdallah and Challal, 2014). Even though, many of such stations utlise solar panels to generate power, there are some that are being run by batteries. One of the major experiment-related problems stated by Gunawardena et al. (2018) was the calibration of low-cost instruments. Such low-cost equipment may not be tested to the same extent as a research-grade equipment, thus leading to unstandardized accuracies and precisions. Reliability of these may also be quite questionable. In addition, distributed sensor stations are of lower measurement flexibility i.e. it is difficult to modify distributed sensors for different tasks as they are often singular in their tasks. For example, stations like Berkeley Telos uses fully customised hardware that requires specialised knowledge and skills to design, develop, use and modify it (Polastre, Szewczyk and Culler, 2005).

These limitations of distributed sensor stations could be overcome by open-source hardware, mainly by using Arduino which is a line of open-source microcontroller development boards designed and developed by the Italian company Arduino (Gunawardena et al., 2018).

Among the many previous work with Arduino-based environmental monitoring stations, commercial Wi-Fi connected sensor station namely Sentinel Microi that was used by Young et al. (2014) was able to produce accurate results at a low-cost, after incorporating a custom radiation shield to it. However, this was only capable of measuring one environmental parameter i.e. air temperature. Even though, (Young et al., 2014) in their study, demonstrated the possibility of building low-cost monitoring stations, they also demonstrated the need for additional development to make such stations more capable in accurately measuring more parameters such as the humidity, wind speed, barometric pressure, and solar radiation.

Another attempt was the multiple open-source Arduino-based sensor systems described by Fisher and Gould, (2012) that were utilised to measure environmental parameters in a forested setting, along with the water use in agricultural applications. However, these stations used only a few sensors, limiting its flexibility in the sensors that could be used. Further, they were run by batteries, and solar panels, which necessitated regular batter changes. Another drawback was that the accuracy of sensors was not explored in depth, hence was not quantified.

Gunawardena et al. (2018) presented a Local Energy-budget Measurement Station (LEMS) through their study which was a small, open-source weather station that measured environmental properties in the atmospheric surface layer (ASL): relative humidity, air temperature, wind speed and direction, barometric pressure, incoming solar radiation, and soil moisture. LEMS was designed to be low-cost, durable, and easy to deploy in various types of terrain. Cost of a fully instrumented LEMS was approximately USD 1000. However, data from LEMS has experienced radiation errors in the temperature and relative humidity, and according to field tests, anemometer was unable to perform well at low wind speeds. Moreover, LEMS was prone to high power consumption which was its largest practical problem.

As previous studies demonstrated, many researchers have focused on developing low-cost environmental monitoring stations, with some based on open-source hardware and software. Open-source hardware and software based systems are capable of offering everything that commercial distributed sensor systems and met towers would offer, but with a lower cost and increased flexibility.

Nevertheless, a recurrent issue when setting up small-scale weather monitoring systems that are mainly funded for a set period of time is the operational restrictions due to financial constraints (Takahashi, Mikami and Takahashi, 2011), and this is highly applicable to such research projects carried out in developing countries. Development of a novel environmental monitoring system and setting up a new weather station in this context, involves a few crucial problematic aspects such as finding relevant stakeholders, appropriate technical and network infrastructure, successful knowledge transfer which includes sharing of high quality data, successful communication, continuous and successful maintenance, public engagement and educational outreach that need to be addressed in order to sustain such low-cost weather monitoring stations. Thus, having an understanding of how sustainable is a particular weather monitoring station, especially in terms of quality of data it produces, including accuracies, its maintenance aspects, and mainly the cost of such a fully instrumented station against other research-grade stations is vital to make improvements in the research and development of these low-cost weather stations. Hence, this study focuses on exploring the level of sustainability of the 4ONSE weather station in the hope of understanding how sustainable an open-source, low-cost and non-conventional weather monitoring system could be.

3. Methods and Materials (750-1500)

3.1. 4ONSE system deployment

The 4ONSE project is a collaborative research project between University of Moratuwa, Sri Lanka and University of Applied Sciences and Arts of Southern Switzerland (SUPSI). This project was initiated at a time where the necessity of a low cost, non-conventional and dense weather station network is greatly demanding due to unprecedented weather condition and climate related disasters in Sri Lanka.

The weather station was developed as an Arduino Mega2560 based embedded system. Its primary functions are collecting data from all the sensors, processing some of the data before sending them to the server, controlling and communicating other peripherals including SD module, real time clock module (RTC), fan controller and GSM module. Upon receiving all the data from all the sensors, it will send the data to the server with 10 minutes time interval. Sensors of the system can detect eight parameters including air temperature, pressure, solar radiation, humidity, wind direction, wind speed, rainfall and soil moisture. At the beginning, the sensors were selected primarily considering the factors such as cost, measuring range, accuracy level and market accessibility to sensors. However, during the development and deployment stages, it was realized that some of the sensors showed very less or no capability in coping with the country's climatic condition. Therefore, some sensors had to replace and modify as per the climatic condition of the country. Table 1 shows the finally selected sensors of the 4ONSE monitoring system.

Table 1: Sensors used in the 4ONSE monitoring system

Parameter	**Selected sensor**
Air temperature	DS18B20
Relative humidity	BME280
Atmospheric pressure	BME280
Wind speed	Anemometer with mechanical 3 cups
Wind direction	Wind direction sensor
Rainfall	Davis Aerocone Rain Collector - 6465
Solar radiation	Sl1145 UV IR Visible sensor
Soil moisture	YL - 69

The power supply unit is composed of 30W solar panel, 12V 25Ah rechargeable battery, 100W solar panel voltage controller and power regulators to keep voltage in the recommended range of electronic items.

The selected basin to deploy the 4ONSE stations is Deduru Oya basin, which is the 4th largest river basin of Sri Lanka. The deployment was begun on 6th March 2018 and installation of 27 stations in the basin was completed on 21st July 2018. Under the project, two types of stations have been developed: 4ONSE-MOD (4ONSE Modular prototype) and 4ONSE-PCB (4ONSE Printed Circuit Board prototype). The symbols "M" and "P" in Figure 1 denotes the locations of the 4ONSE-MOD and 4ONSE-PCB respectively.

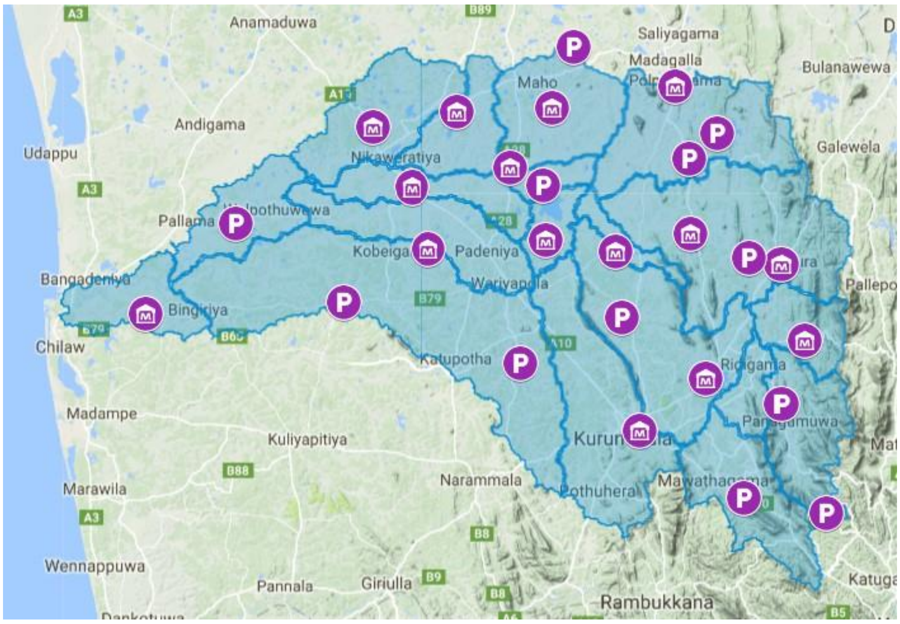

Figure 1: Locations of the 4ONSE-MOD and 4ONSE-PCB stations

3.2. Conformity with WMO standards

WMO (2003) describes the requirements of observational data in terms of global, regional and national scales and according to the application area. WMO (2014) has recommended ranges and resolutions for measuring certain meteorological variables. Table 2 shows the 4ONSE station and WMO recommended ranges and resolutions.

Table 2: Ranges and Resolutions of 4ONSE system and WMO standards

Parameter	**Selected sensor**	**Sensor specifications**		**WMO standards**	
		Range	**Resolution**	**Range**	**Resolution**
Air temperature	DS18B20	-55^0C to $+125^0C$	±0.5°C (from -10°C to +85°C)	-80^0C to $+60^0C$	0.1K
Relative humidity	BME280	0% to 100%	±3%	0% to 100%	1%
Atmospheric pressure	BME280	300 to 1100hPa	±1 hPa	500 to 1080 hPa	0.1hPa
Wind speed	Anemometer with mechanical 3 cups	0 to 32.4 ms^{-1}	±1ms^{-1}	0 to 75 ms^{-1}	0.5ms^{-1}
Wind direction	Wind direction sensor	0^0 to 360^0 (16 directions)	45^0	0^0 to 360^0	1^0
Rainfall	Davis Aerocone Rain Collector - 6465	0 to 999.8mm/day	0.2mm	0 – 500mm/day	0.1mm
Rainfall intensity		±4% of total or 0.2mm up to 50 mm/h, ±5% of total or 0.2mm up to 100 mm/h whichever is greater	0.2mmh^{-1}	0.02mmh^{-1} to 2000 mmh^{-1}	0.1mmh^{-1}
Solar radiation duration	Sl1145 UV IR Visible sensor	0 to 24h	60s	0 to 24h	60s
Net solar radiation		IR Sensor Spectrum: Wavelength: 550nm-1000nm (centered on 800) Visible Light Sensor Spectrum: Wavelength: 400nm-800nm (centered on 530)	1Jm^{-2}	Not specified	1Jm^{-2}
Soil moisture	YL - 69	0 to 100%	±1%	Not specified	Not specified

The measuring ranges of relative humidity, atmospheric pressure, wind direction, daily rainfall and solar radiation duration are conformed with WMO standards. Since the country's temperature has never dropped below 0^0C, the measuring range of DS18B20 is adequate to measure the temperature of the country. Besides, the positive range of the DS18B20 sensor comes under the range specified by WMO. The maximum speed level measured by the 4ONSE station is 32.4 ms^{-1}. Wind speed is the main parameter of determining the severity of tropical cyclones. As per Table 3, the wind speed of the 4ONSE system is adequate to determine four stages of cyclonic disturbances: low pressure area, depression, cyclonic storm and severe cyclonic storm.

Tale 3: Classification of cyclonic disturbances (low pressure systems) for Sri Lanka

Type of disturbance	Corresponding wind speed
Low pressure area	Wind speed less than 17 kt (9 m/s)
Depression	Wind speed between 17 and 33 kt (9 and 17 m/s)
Cyclonic storm	Wind speed between 34 and 47 kt (18 m/s and 24 m/s)
Severe cyclonic storm	Wind speed between 48 and 63 kt (25 and 32 m/s)
Very severe cyclonic storm	Wind speed between 64 and 119 kt (33 and 61 m/s)
Super cyclonic storm	Wind speed between 120 kt and above (62 and above)

Source: WMO, 2010

Further, as illustrated in Figure 2, the Deduru Oya basin belongs to the 25 – 35 knots (13 – 18 ms^{-1}) and 35 – 45 knots (18 - 23 ms^{-1}) areas, where the maximum sustained wind speed when tropical cyclone crossed or vicinity of Sri Lanka during the period of 1958 – 2009. Therefore, the measuring range of the wind speed sensor is adequate for the area.

WMO (2008) suggests rainfall should be read to the nearest 0.2mm and, if feasible, to the nearest mm. Therefore, for the 4ONSE station, 0.2mm resolution Davis Aerocone Rain Collector has been used to measure the rainfall. Although the resolutions of other variables such as temperature, relative humidity, atmospheric pressure, wind speed and wind direction do not exactly fit with the resolution standards of WMO, compared to the other commercially available high cost weather stations, resolutions of 4ONSE station has shown better quality in terms of sensor resolution (Table 4).

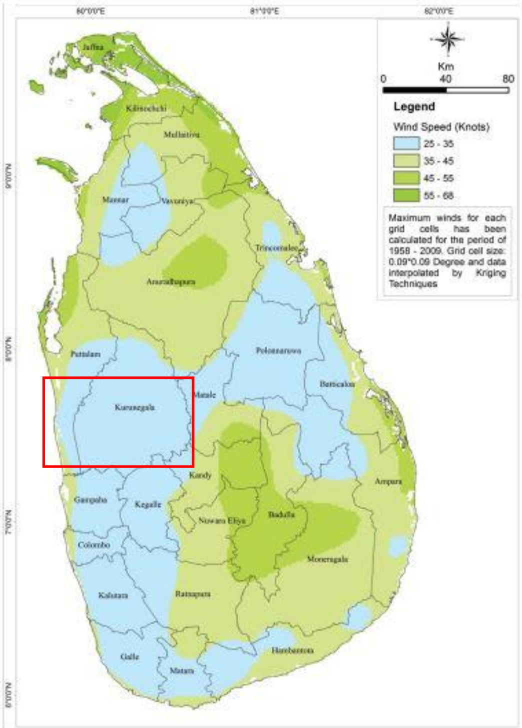

Figure 2: Maximum sustained wind speed map when tropical cyclone crossed or vicinity of Sri Lanka (1958 – 2009)

Source: Disaster Management Center, 2009

3.3. Cost effectiveness of the 4ONSE system

The 4onse system was compared with some randomly selected wireless and automatic weather stations in the market which measure similar parameters (Table 4). Although there are varying accuracy levels of the parameters measured by each system, the 4ONSE system is capable of measuring eight parameters with a relatively low cost.

Table 4: Comparison table of costs and accuracy levels of 4onse system and some of the automatic weather stations in the market

Measured Parameters & other available features	**4onse system**		**Vantage Pro Plus Station**		**MetPak RG Weather Station**		**Rainwise PORTLOG 805-1018 Portable WS**	
	Availability	**Accuracy**	**Availability**	**Accuracy**	**Availability**	**Accuracy**	**Availability**	**Accuracy**
Rainfall	√	0.2mm	√	0.2mm	√	0.2mm	√	0.5mm
Wind speed	√	0.2-0.4m/s	√	12m/s	√	12m/s	√	+0.01m/s
Wind direction	√	±3°	√	±3°	√	±3°	√	$\pm 3^0$
Temperature	√	$\pm 0.5^0$C	√	±0.1°C	√	±0.1°C	√	$\pm 1^0$C
Relative humidity	√	±3%	√	±0.8%	√	±0.8%	√	2%
Barometric Pressure	√	±1hPa	√	±0.5hPa	√	±0.5hPa	√	±0.5 hPa
Solar radiation	√	$1Jm^{-2}$	-	-	-	-	√	±5%
Soil moisture	√	±2%	-	-	-	-	-	-
Wireless communication	√		√		√		√	
Cost	USD 750		USD 1,295.00		USD 2611.20		USD 3,595.00	

3.4. System design to cope with tropical climatic condition of the country

The most challenging task is to maintain the durability of the system by protecting the system from intense temperature, humidity, dust and entomological activities, which are more pronounced in the tropics than in other regions of the world. In here, the word ‘tropical’ specifically means places near the equator. As a tropical country which is located closer to the equator, surrounded by Indian Ocean, Sri Lanka has a diversified climatic condition enriched with heavy monsoonal rainfalls and hot temperatures in all year round.

From the starting date of 4ONSE station deployment, until now, most of the problems encountered in stations are occurred as a result of oxidization. Especially the BME280 sensor and soil moisture sensor had the oxidization problems. BME280 sensors usually send relative humidity value as 100% when they are not properly working. Accordingly, the sensors bought from the Chinese market were replaced with a good quality BME sensor bought from SparkFun online retail store. At the same, another set of BME sensors were bought from the local market and CRC plasticote 70 clear protective lacquer was applied to its circuit. It protects and seals electronic devices from water vapor, diluted acids, alkalies and high temperature.

As a remedy for the oxidization problem in soil moisture sensor, a new type of soil moisture sensor was designed using stainless steel tubes.

Moreover, the project team visits each station at least twice a week for check its status. The project members of SUPSI has made an Android application called ODK Collect v1.16.1 for reporting and recording the status of the stations. It also has some instructions on maintaining the sensors and other parts of the system, i.e. cleaning the temperature sensor with distilled water, clean the pressure sensor with dry cloth, open the throat of the rain gauge to check whether it is level, the solar radiation shield is clean from debris, etc.

4. Discussion & Conclusion

One of the methods of monitoring the environment is measuring and analyzing the environmental parameters by placing sensors in monitoring stations. In recent years, the advancement of open source hardware has showed significant reductions in costs of sensors used for environmental monitoring. During the past few decade, several researchers and hobbyists have developed single and multiple parameter/s based environmental monitoring systems equipped with low cost open source hardware products. Most of the low cost weather stations projects are implemented in African countries to face the weather related challenges. TAHMO (Trans-African HydroMeteorological Observatory), SMS-Lapli (SMS Rain) and WIFA (Weather Information for All) are some of the projects launched in Africa. Therefore, 4ONSE project can be considered as the initial project implemented in Asian context, to monitor the environment in river basin scale. The 4ONSE system is based on the previous researches conducted by University of Moratuwa and International Water Management Institute (IWMI) (Chemin et al., 2014; Chemin et al., 2015) on Open Source Hardware (OSHW) and Free and open-source software (FOSS) based mobile weather stations to capture and transmit data on rainfall, temperature, wind speed, wind direction, light, pressure and humidity. Three main components were used to build this weather station: Weather Shield with GPS, A Sri Lankan version of Arduino Micro-Controller called as “Lakduino” and Data Logger. The 4ONSE station can be considered as a more improved version of the above station, in which the PCB (Printed Circuit Board) of the system comes as a soldered unit which includes sections for all the main circuits and sensors. It was developed as an Arduino Mega2560 based embedded portable system. The system uses renewable energy sources to supply the power to the station using 30W solar panel and 12V 25 Ah battery. In addition, the system is developed as a self-diagnostic system equipped with internal temperature sensor and voltage monitoring meter. The cooling fan inside the system automatically starts when the internal temperature of the system is higher than 37^{0}C. The weather readings can be viewed through istSOS open source software. Three Davis Vantage Pro 2 stations have been purchased as reference stations to check the accuracy of the 4ONSE weather data. One reference station was installed at University of Moratuwa and the other two stations were installed in the Deduru Oya basin for data validation.

The current network coverage of the country equipped with traditional meteorological stations is restricted to certain locations due to high installation and maintenance cost. Most of the weather stations in Sri Lanka are manually operated and data is transmitted vocally over the phone. According to the discussion had with the officers of the Meteorological Department, the cost of each unit is about USD 65,000. Most of the time, the hardware and software of these stations cannot be adjusted to integrate new parameters (Senevirathna, S. and Jayawickrama, V., 2014). As shown in Table 5, the entire 4ONSE system can be built at a cost of 750 USD. Some of the items purchased from the international market have considerable amount of shipping charges. Compared to the other commercially available branded weather stations in the market, the cost of the 4ONSE station is comparatively low. The cost can be further reduced if all the required components can be purchased from the local market. The 4ONSE-MOD station, which was built in Switzerland was built at a cost of 339 CHF since the components were purchased in Switzerland. In addition, the monthly maintenance cost of the system was approximated as follows:

If an officer was appointed for each weather station, he/she will be paid a monthly salary of USD 100. For communication, an approximate amount of USD 10 has to allocate. Hence the total monthly maintenance cost for each weather station is about USD 110.

Table 5: Cost items of the 4ONSE-PCB station

Component	**Cost (USD)**
Sensors and Arduino	
Arduino Mega 2560	10.41
Davis Aerocone Rain Collector - 6465	125.61
Wind Direction Sensor	52
Wind Speed Sensor	37.5
BME280 Sensor	21.95
DS3231 - RTC	1.64
OpenLog	1.71
SIM800	29.66
UV IR Visible Light sensor	7.21
DHT11	1.2
DS18B20	1.33
YL-69	1.93
LM393	1.58
Mounting structure and power supply unit	
Pole	126.57
Battery (12V, 35Ah)	39.87

Solar panel (30W)	31.01
Solar charger/regulator (12V,10Ah)	12.02
Concrete works	15.82
boxes	41.58
Base	15.82
Other	
Miscellaneous electronic items and other works	174 (approximately)
Total Cost	**750**

The measuring ranges and resolutions of the sensors used in the 4ONSE station have shown relatively better conformity with WMO standards and their specifications are adequate to develop the two applications of the project – one application involves developing a tank management model to forecast the variation of tank level of Deduru oya reservoir and the second application involves developing an early warning system to forecast the drought.
Out of the seven sensors, two sensors (BME280 and YL – 69) had to modify as per the tropical nature of the country. As yet, the other sensors found to be consistent with the climatic condition of the country.
Accordingly, this research presents the sustainability of the 4ONSE system in terms of cost, conformity with WMO standards and remedies taken to design the system to suit with the tropical climatic condition of the country.

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