Heliyon 9 (2023) e20784

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Inventing a robust road-vehicle flood level monitoring device for disaster mitigation

Uzoma Ifeanyi Oduah [a,*], Christopher M. Anierobi [b], Olufemi G. Ilori [a]

[a] *Department of Physics, University of Lagos, Nigeria*
[b] *Department of Urban and Regional Planning, University of Nigeria, Nsukka, Enugu Campus, Nigeria*

A R T I C L E I N F O

Keywords:
Flood
Flood level monitoring
Road flooding
Water sensor-probe
Road vehicle safety

A B S T R A C T

Flooding impedes road utility and the frequency has increased across countries of the world owing to global climate change phenomena. Global road flooding casualties have risen from 371,800 in 2015 to 842,000 in 2017 resulting to economic losses valued at approximately US$71 billion. Existing devices that offer warning signals on safe threshold during flooding are predictive in nature and based on complex technologies that are cumbersome and rather expensive thereby affecting the attractiveness to low-economy societies of developing countries. There is therefore a dare need for better inventions towards greater mitigation. This paper presents an adaptive, affordable, robust, efficient and effective road vehicle flood level monitoring device for detecting rising flood on roads above a user defined safe threshold to mitigate road flooding disasters. The device operates on the principle of level conductivity sensor. The developed device offers interoperability with Google map enabling the level of flood on road to be accessed by road users online when fully commercialized. By this, road users are aware of the dangerous levels of flood to enable them use alternative routes. The study therefore recommends for adoption of mandatory inclusion of this invention on roads towards averting the usual road flooding hazard in Africa.

1. Introduction

Information on the variations of onsite flood levels on the roads prone to flood are presently unavailable to the road users thereby exposing them to risks and dangers of motor accidents due to excessive flooding of the road. If road users are aware of the level of flood on the roads before attempting to drive through, then they can avoid dangerously flooded roads and follow alternative routes. The scientific goals of this research is therefore to develop a product that will warn road users of dangerously flooded roads, the level of floods on the road, and to generate data on flood levels for further scientific studies. The outcome of the study will mitigate accidents associated with flooded roads and help in decongesting traffic during rainy season.

The rapid spike of the number of casualties of road flooding and the associated huge economic losses demands urgent solutions given the tremendous rise of global road flooding casualties in recent times. Incidentally, the risks associated with global climate change have manifested in various forms in various regions. This research work identifies high cost, inappropriate sensor technology and inefficient implementation as the challenges that limit the existing road flooding level caution devices. The identified research gaps make the existing technologies unsuitable for low income countries of Africa which are the most vulnerable to road flooding.

* Corresponding author.
E-mail addresses: uoduah@unilag.edu.ng (U.I. Oduah), christopher.anierobi@unn.edu.ng (C.M. Anierobi), ilori_olufemi@yahoo.com (O.G. Ilori).

https://doi.org/10.1016/j.heliyon.2023.e20784
Received 4 March 2023; Received in revised form 5 October 2023; Accepted 6 October 2023
Available online 11 October 2023

Consequently, this paper presents the invention of a simple, robust, adaptive and affordable device to address the limitations of the current road flooding warning solutions suitable for Africa.

In recent times, unprecedented rise in temperature, melting of ice in the Polar Regions as well as heavy rain falls and flooding in the Great Plains, Midwest, and Northeast among others are associated with global climate change. Such rise in floods is attributed to a warming planet and rise in sea level [1]. The findings of the various climate studies presented in literature predicts that rainfall intensity will grow by 40% if the toxic emissions that cause global warming continue unabated [2,3]. Previous work [4] illustrated the various multiple global climate models for estimating the exposure to flooding in a warmer future climate and warned about global flood risk rising exponentially at the end of this century. However, the inter-annual fluctuations and variability will depend majorly on the planned adaptation before any significant warming and the global implemented prevention strategies [5–7].

The available flood warning devices are unattractive due to their high cost and inability to function on poorly constructed muddy roads common in low-income countries [8]. The state-of-art technologies like the Space-borne earth observation technology using commercial satellites for the acquisition of flood images are capital intensive and are not an option for countries that cannot afford quality roads. Some of these identified advanced technologies for monitoring flood and their challenges are presented in Table 1.

The Sustainable Development Goals (SDG) target of a 50% reduction in road traffic deaths and injuries by 2020 was not achieved partly owing to the uncontrolled and unmonitored vehicle traffic on flooded roads in most low-income countries [10]. Presently, the Google map does not have the capacity to indicate flooded roads or level of floods on the road. There is therefore an imperative need for road users to be aware of the level of flood on the road even before approaching a flooded spot on the road or attempting to drive through hence, this work.

The impact of the increase in flood has led to undesirable flooding of roads to levels that are dangerous to motorists [11–13]. For instance, motorists risk drowning with their vehicles submerged in water arising from incessant high levels of flood on roads. Furthermore, it is also important that the speed limit close to potential flood spots on the road should be low enough for motorists to drive cautiously [14]. Generally, flood is classified into three based on the source and the duration [15]. The flash flood takes few hours to return to normal and is usually caused by less than 6 h rain. The monsoon flood occurs more than 6 h rain while the Tidal flood is from overflow of inland caused by inadequate drainage systems. It is important that the technologies deployed in detecting and monitoring flood on road are dynamic to function in any of the classes of flood. The emergence of mobile technology and internet connectivity has improved the effectiveness of flood response, recovery, and data collection however lack of internet is a limitation in low income countries. Advanced technology involves the use of satellite images to map the road networks as implemented by the Humanitarian Open-Street Map Team, and the Standby Task Force and Digital Humanitarian Network. Unfortunately, low-income countries cannot afford these advanced approaches [16]. Thus, the present work was motivated by the desire to provide a safeguard in the form of a simple flood level monitor to act as early warning system for road users in time of road flooding. Its operation implements remote sensing of road flooding real time online levels when successfully integrated with Google map, and also provide data for forecasts.

Some flood level detectors operate with pressure sensors which are susceptible to various variations in environmental factors such as high temperatures. The existing flood warning devices with all their limitations are used in different countries; but predominantly used in Philippines, Honduras among others. The available flood detection devices with their limitations are presented in Table 2.

2. Materials and methods

2.1. Conceptual framework and design of the invented road vehicle flood level monitoring device

The principle of detecting water level using electrode sensors is applied in this work. The water acts as a conducting channel which completes the electric circuit between the electrode probes. Initially, the electrode probes are open circuit positioned at calibrated levels. As the water level rises from the reference probe to each target level thereby making contact with the electrode probe, it completes the circuit and becomes a closed switch. The corresponding arrays of LED are activated and short-message-service (SMS) message is sent to enrolled mobile phone numbers via the Global system for mobile communication (GSM) module.

The block diagram of the development process for the invented Road Vehicle Flood Level Monitoring Device is shown in Fig. 1.

In the present work, a novel, reliable, adaptive and cost effective road flooding level monitoring device was designed, constructed and implemented by mounting it on street lights or poles with power supply. The invented Road Vehicle Flood Level Notification

Table 1
Identified flood monitoring solutions and their challenges.

Flood system monitoring solution	Organisation	Data/service Type	Challenges
MODIS/landsat NRT flood maps (Estimated cost: $5.2 Million)	NASA/GSFC	MODIS mapping (Landsat mapping on request only)	Cloud masking; Integration of SAR uncertainty.
Dartmonth Flood Observatory (DFO) (Estimated cost: $10 Million)	NASA/University Colorado, Boulder	MODIS-based mapping	Cloud masking; SAR-derived maps only for selective events.
River Watch (DFO) (Estimated cost:$7.5 Million)	NASA/University Colorado, Boulder	Radiometry-based discharge	More sites needed, linking with flood model.
CEOS Flood Pilot (Estimated cost: $12 Million)	CEOS	Flood pilot Research and Development	Image licensing.

Source: (Schumann et al., 2018) [9].

Table 2
Flood detection devices and their limitations.

S/N	FLOOD DETECTION TECHNOLOGY	DESCRIPTION	LIMITATIONS
1.	Ultrasonic sensors	Uses high frequency sound-waves to measure the flood levels remotely without physical contact with the water.	Renders inaccurate results with foamy and muddy water.
2.	Combination of ultrasonic range finding with remote temperature sensing	Implements a combination of L1-regularized reconstruction and artificial neural network to process measurement of flood level data.	Susceptible to environmental perturbations caused by high water currents during measurement of flood levels. Relatively expensive.
3.	Wireless sensor networks (WSNs)	Uses non-contact camera-based sensors to detect flood.	The device can only provide binary information either presence of flood or not.
4.	The Flashing Beacons	Deploys a roadside embedded sensor that warns motorists to slow down when approaching a slippery or wet road.	It does not measure the flood level.

Source: Authors' Compilation, 2021.

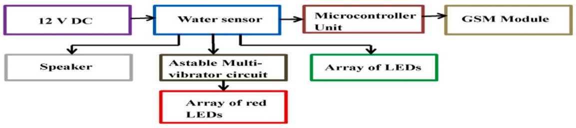

Fig. 1. Block diagram of the Road Vehicle Flood Level Monitoring Device.
Source: Authors

Device is designed to trigger alarm and flash a red light whenever the flood level on roads exceeds a permissible threshold for motorists. It also activates the GSM module to deliver SMS messages to enrolled users. The device is calibrated into four different levels and mounted on the street light/poles with the water sensors positioned in such a manner that they detect water levels at the user determined safe and unsafe depths. The introduction of the device will reduce road hazards caused by floods on roads. A mandatory inclusion of the developed device on all roads with advanced warning traffic symbol for flood is proposed. The device interoperability with Google map will enable road users to view the level of flood on roads online and therefore determine the best route to take during

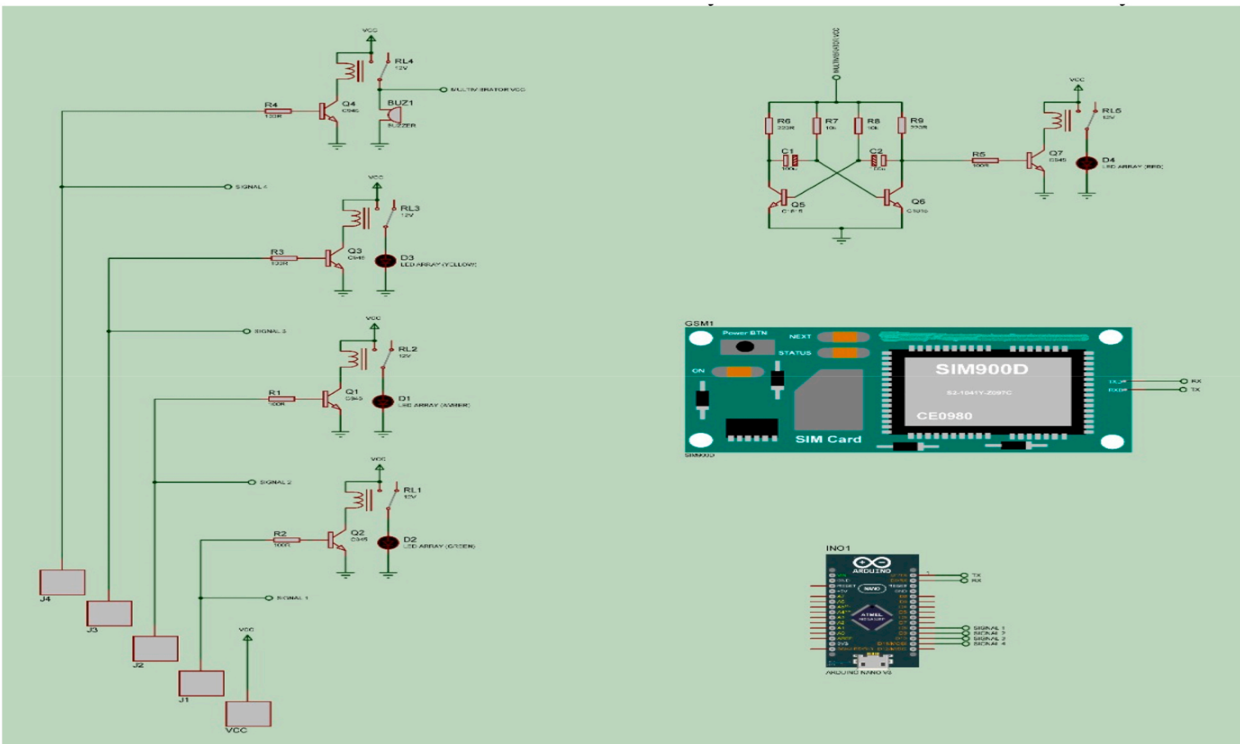

Fig. 2. Circuit diagram of the Road-vehicle flood level monitoring device.
Source: Authors

flooding of roads.

The power source for this prototype consists of a 12-V battery. However the device is to be installed on street lights enabling it to share power from the street lights for the recharging of the 12-V battery when the streetlights are 'On' at night. The voltage source is fed into the water detection circuit comprising of four bipolar-junction transistors, arrays of green, yellow, light orange, and red light emitting diodes (LED) and four metallic water probes. The circuitry for the connection is illustrated in Fig. 2. The circuit board is packaged inside a water tight plastic container to ensure protection from water moist and corrosion. The arrays of LED's are for detecting the various target depths. Previous work [22] demonstrated the water sensor wiring architecture that can be applied for flood detection. The green, yellow, and light orange LED's indicates the various rising water levels which vehicles can pass. But the red LEDs were used for the highest depth indicating danger "no entrance". The negative-positive-negative (NPN) bipolar junction transistors were used because they possess fast switching time since electrons are their majority carriers [23]. The connection of the transistors is in the common emitter mode with the emitter connected to the ground as shown in the circuit diagram in Fig. 2. The base is the input to the Bipolar Junction Transistor (BJT) while the collector is the output. An input resistor of 100Ω is connected to the base of each of the BJT and a relay which activates the LED array.

The NPN transistor that is linked to the highest depth water probe is connected to an astable-multivibrator circuit. The astable-multivibrator circuit consists of two NPN bipolar junction transistors connected back to back with the output of one fed into the input base of the other as implemented previously [24]. The switching time of the two transistors is determined by the resistors-capacitors time constant. The circuit generates oscillations which are transmitted to the array of red LEDs which starts blinking, while the speaker is also activated simultaneously. This danger warning alarm is an indication that vehicles are not allowed to pass.

2.2. Component sourcing integration and prototyping

The packaging of this invented device was designed to suit and adapt to the prevailing conditions of the operating environment even as experienced in developing countries with most poorly constructed roads. A hard plastic material is used for the construction of the water column. This prevents the device from rusting and protects it from moisture. The inlet opening is shielded with three different gauze casing with varying pore spaces to sieve water inside to prevent dirt from covering the water sensor probes. The three layer casings contain pore spaces to allow easy flow of water inside and outside the water column as the flood level rises or falls. The aperture of the gauze materials are graded with the outermost cover with size 0.8×0.8 cm^2, followed by the middle gauze aperture 0.5×0.5 cm^2, and the innermost gauze aperture 0.2×0.2 cm^2. So the water column does not trap water inside but instead its water content level maintains the same level with the flood. The arrays of red LEDs on the light display unit are mounted on the streetlight at a height, 2.5 m and above in such a manner that the light is visible at a distance about 20 m away from the mounted support structure.

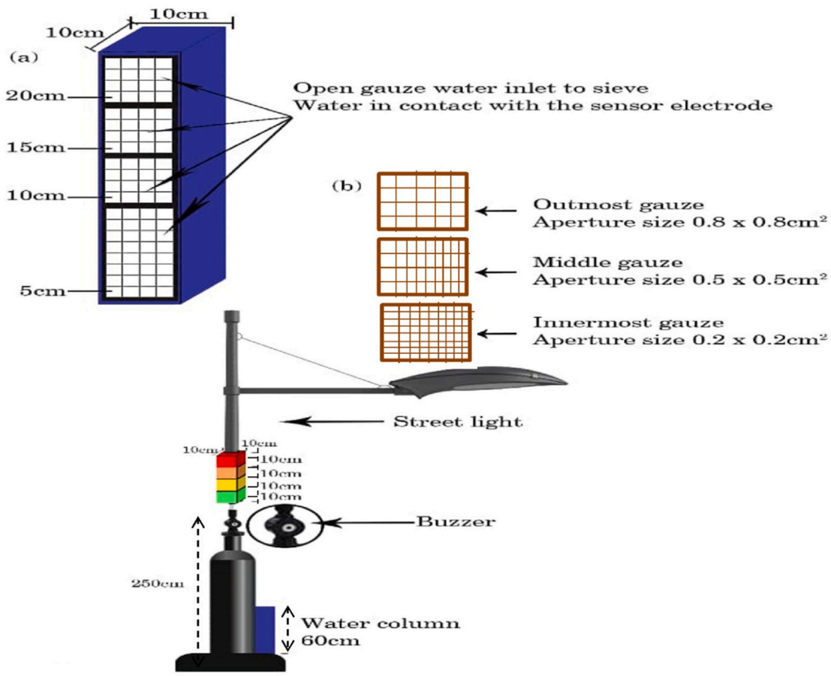

Fig. 3. (a) The Road Vehicle Flood Level Monitoring Device describing the water column. (b) The gauze with different aperture size. (c) The position of the LEDs.
Source: Authors

The developed Road Vehicle Flood Level Monitoring Device is described in Fig. 3a, b, c and 4. The installation of the device on a street light is demonstrated with Fig. 3c while Fig. 4b shows the mounting of the device on a pole. Alternatively the invented device can be mounted on a pole with solar panel or other power supply to recharge the battery. An illustration of the operation of the developed device is shown in Fig. 4a. The costing of the developed device is presented in Table 4. The price range of other variants of flood detection systems available in the market are between $250 (Two hundred and fifty Dollars) to $1000 (One thousand Dollars) which places the developed device much cheaper when commercialized. At such, the invented device is far more affordable than the existing ones. All the components of the device are recyclable and reusable hence should be recycled and reused upon replacement.

2.3. Details of the developed road vehicle flood level monitoring device

The developed road vehicle flood level monitoring device consists of the water column and the light display unit with a buzzer attached to the side. The support framework structure is designed to be mounted on any existing streetlight at the vehicular road location prone to flood. The water column contains three different gauze of reducing aperture sizes 0.8×0.8 cm^2, 0.5×0.5 cm^2, and 0.2×0.2 cm^2 respectively as shown in Fig. 3b. The gauze sieves the floodwater entering the column such that it does not admit materials that will mask the sensor probes. The light display unit is in four different segments, green, yellow, light orange and red arranged in order of rising flood levels as described in Fig. 3c. The buzzer is synchronized with the array of red LEDs to trigger On simultaneously. A support framework pole made of a galvanized mild steel pipe of diameter 10 cm and length 300 cm may be implemented on locations where there are no streetlights as deployed in the testing of the developed device shown in Fig. 4b. During commercialization, the device will be mounted on existing streetlights so the support framework will only be needed where there are no streetlights. This device is powered by a 12 V DC battery for the demonstration of the operation of the device. Other power sources such as solar modules, power grid through the existing streetlights and any other economically viable electric power supply may be deployed for the operation of the device.

3. Results

The result of this research work addresses the research question bothering on an alternative improved invention to the limitations of the existing and available flood warning devices. This includes addressing limitations that makes the existing road flooding caution devices unattractive and therefore unavailable on roads needing the device. The study further explored the question on actualizing the

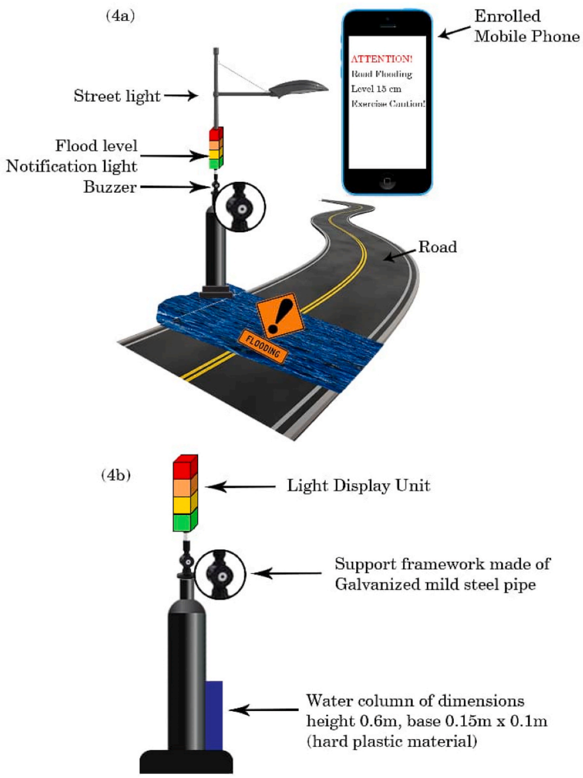

Fig. 4. a). Illustration of the operation of the road-vehicle flood level monitoring device showing a delivered text message of flood level. 4(b). Schematic of the developed device mounted on pole.
Source: Authors

Table 3
Flood level report delivery time for the developed road vehicle flood level monitoring device.

Flood levels	Time lapse before SMS indicating flood level was delivered to enrolled phone in Seconds				
	First Trial (s)	Second Trial (s)	Third Trial (s)	Fourth Trial (s)	Fifth Trial (s)
5 cm (Green light)	1	1	4	3	1
10 cm (Yellow light)	1	1	1	2	2
15 cm (Orange light)	1	5	1	6	2
20 cm (Red light)	2	1	1	2	1
15 cm (Orange light) receding	1	9	5	7	1
10 cm (Yellow light) receding	1	6	1	1	2
5 cm (Green light) receding	2	1	1	5	7

Source: Authors

Table 4
Costing of the invented Road Vehicle Flood Level Monitoring Device.

Item	Quantity	Unit cost ($) USD	Cost ($) USD
Light emitting Diodes (LED indicator lights)	36	$0.45	$16.20
Bipolar Junction Transistors (C945)	6	$4.70	$28.20
Bipolar Junction Transistors (C1815)	2	$4.70	$9.40
Resistors (100 Ω)	4	$5.99 for a pack of 100 pieces	$0.24
Resistors (220 Ω)	6	$6.43 for a pack of 100 pieces	$0.39
Resistors (10 kΩ)	2	$2.63 for a pack of 2	$2.63
Capacitors (100 μF)	2	$5.57 for a pack of 5 pieces	$2.23
Relay (10ADC, 12 V, 400 Ω)	5	$0.95	$4.75
Speaker (Electric Buzzer)	1	$4.49	$4.49
SIM900D	1	$4.00	$4.00
SIM card	1	$5.00	$5.00
Arduino UNO	1	$11.97	$11.97
PCB board	1	$12.99 for a pack of 40 pieces	$0.33
Water filter gauze	3	$5.00	$15.00
Plastic Casing for water column and Packaging the device	1	$50.00	$50.00
Water sensor copper wire probes		$10.00	$10.00
Total			**$164.83**

Source: Authors

invention of an adaptive, affordable, robust, efficient and effective road vehicle flood level monitoring device for detecting rising flood on roads above a user defined safe threshold to tackle road flooding disasters.

3.1. Testing and validation

The operation of the invented device was tested to ensure prompt detection of flood level on roads. The developed electronic flood level notification device was powered with a 12-V rechargeable battery and placed vertically upright in an empty 500 L open ended plastic tank. Few bowls of sand mixed with mud were poured onto the floor of the tank to make it appear dirty like flood water. Water was now passed gradually into the tank with a hose and the solution stirred to form very slurry dirty water. The water probes are the sensor electrodes. It was observed that the first arrays of green LEDs switched on immediately the water level got to 0.05 m touching the first sensor electrode. As the water level rose to the second sensor electrode, the second arrays of yellow LEDs light were triggered on. Also the third arrays of orange LEDs light were triggered on immediately the water level got to the third sensor electrode. When the water level got to the fourth sensor electrode, the arrays of red LEDs immediately started blinking followed by a very laud audible buzz from the speaker. The caution alarm sounded continuously and simultaneously with the blinking red light from the arrays of red LEDs. The device also sent SMS alert to the enrolled GSM numbers. Furthermore, the water level was now reduced gradually by opening a water outlet at the bottom of the tank. It was observed that the red LEDs switched off simultaneously with the alarm immediately the water level dropped below the corresponding sensor electrode. Also, the other arrays of LEDs switched off as the water level dropped below the sensor electrode which respectively controls them. The Road Flooding Level Monitoring Device performed well with each arrays of LEDs switching on promptly as the water level touched the controlling sensor electrodes. Rather than being predictive, the invented device simply monitored Road Flooding Level according to the prevailing situations by adapting to real time existing conditions.

3.2. Effectiveness and efficiency of the invented device

The invented Road Vehicle Flood Level Monitoring Device is designed to be mounted on existing streetlights. This is designed to reduce cost of erecting poles. The close spacing of the device enables it to have a far wider road network coverage compared to other existing technologies that are positioned at a spot. The staggered positioning of the device along the road allows it to monitor levels of flood even on poorly constructed roads with undulating topography which are very prevalent in underdeveloped and developing countries of Africa. The flood sensing technology, the water probes architecture, the numerous number of the device staggered and mounted on streetlights and the very wide road network coverage all makes the developed device highly effective and efficient in monitoring flooding of roads. To deal with vandalism, we propose that protective iron-rod bars constructed as burglar proof should be wrapped around each mounted device to guard it. Also positioning closed circuit television (CCTV) monitor cameras at the location will go a long way in securing the device.

The advantages of the developed product are in its sensor architecture which delivers real-time online reports of levels of flood on the road not based on predictions; the wide area coverage achieved through the installation technique of mounting on streetlights; ability to function on flooded poorly constructed muddy roads; low cost; and its interoperability with Google maps.

3.3. Simulation of field test for the developed device

The developed road vehicle flood level monitoring device was mounted at the lagoon front road close to lagoon at University of Lagos, Akoka Campus, Lagos. The water from the lagoon was channelled to the road causing the road to be flooded. As the flood entered the water column of the device up to about 5 cm, the first water sensor probes activated the array of green LED lights. When the flood level rose to the second and third sensor probes, the yellow and orange lights triggered on in response to the flood levels. As the flood level reached the fourth sensor probe at about 20 cm, the array of red LED's switched on and the warning alarm simultaneously triggered on. The SMS messages were received on the enrolled phone numbers indicating the flood levels. The channel of the flood was gradually blocked reducing the flood level on the road. As the flood level dropped below the fourth sensor probe, the red light switched off and the warning alarm stopped. Gradually, all the lights switched off in sequence as the flood level dropped below all the sensor probes with SMS messages delivered indicating the new flood levels accordingly as the flood receded. The entire exercise was repeated five times and the time for the delivery of the SMS messages for the flood levels recorded and presented in Table 3. The developed device was confirmed to deliver online real time report of the flood levels within the calibrations of the water sensor probes positioned in the water column. The simulation demonstrated the effectiveness and efficiency of the device as it delivered reliable reports. The water sensor probe levels are made adjustable to suite the terrain where the device is to be mounted.

The delay in the SMS alert was attributed to the stability of the telephone mobile network at the point of transmission. During poor telephone network, the delay is longer.

4. Discussion

The applied sensor technology is a continuity level conductivity sensor since water is the major component of flood. Conductivity level sensors are effective, efficient and very suitable for detecting the depth of water on flooded roads compared to ultrasonic sensors and other sensor technologies [25–27]. The technology requires metallic electrode rods as sensing probes. Each electrode needs at least two contact points to function; one electrode point is a reference point positioned at the base of the container, while the other is connected to a specific defined level. Multiple water level detection will need electrode probes for each target level.

There exist many road flooding monitoring devices that have been commercially deployed for tracking road flood levels. But most of these devices are presently not widely deployed in several flood prone roads because their functionality is based on complex technologies that are cumbersome and expensive [17]. Also, their operations are not suitable for muddy roads encountered in most developing and underdeveloped countries because of the limitations owing to their sensor architecture. At such, this invention was motivated by the need to address the challenges with the current range of road flooding monitoring devices.

One of the ranges of flood level monitoring device is the flashing beacons. The flashing beacons are used mainly to detect wet, slippery and flooded roads. The sensors are not suitable for dirty muddy water which occurs mainly in poorly constructed roads experienced in developing countries of Africa. Its operation relies on Flashing Beacon Controller Remote Series 3580 performance [18]. The same applies to the use of ultrasonic sensors because they sometimes deliver wrong results with slurry muddy dirty water. It is so because ultrasonic sensor technology operates by emitting high frequency acoustic waves between 20 kHz and 200 kHz that are reflected and detected by emitting transducer.

The other existing flood warning systems are not designed specifically for flooding of roads rather they are hinged on flood forecasts based on information collected from specialized meteorological stations [19,20]. Also, they function with predictions by monitoring of the current hydro meteorological situation. They are based on distributed hydrological simulation of numerical ensemble weather predictions with global coverage. The float actuated flood warning system with remote telephone reporting is a US patented device that is stationed at only one strategic location. It warns communities at riverine areas of rising water levels and is usually positioned underground in wells to detect rising water above sea level. Other flood warning devices deploy rising water in sump pits for their operation [21].

4.1. The strength of this study

The applied methodology relied on a simple, efficient water sensor technology using common electronic components, and wide coverage implementation mechanism that is adapted for poorly constructed roads prevalent in remote areas of Africa. The developed device delivers real time online report of flood levels, not a predictive approach. It implements very low cost simple water sensor architecture that can operate in muddy poorly constructed roads. The installation on streetlights enables it to have very wide area coverage of the roads. The planned integration of the system to Google-Map means that the generated data will be available to users globally and at their comfort which summarizes the novelty of this work. Recent civil engineering road construction models recommends that major roads that have greater impedance during floods should be distributed throughout the region so that mobility is less affected by floods [28–30]. Implementing the developed device will enable the road users to be aware of level of flooding on the roads promptly so as to use the alternative distributed roads. The cost of the device is presented in Table 4 with a total sum of $164.83.

Progress is being made towards the commercialization of the developed device. The invented device is a prototype which can still be modified to enhance its capabilities before commercialization. The negotiations with Google map for the integration of the device to enhance its functionalities is one of the key commercialization strategies. The network integration capability of the developed device is simple and can be demonstrated after obtaining permission from Google. The Google Maps Pro addon provides a platform to register the app project on the Google Application Programming Interface (API) console and get a Google API key to be added to the app.

The device water column uses three water filters with different aperture to sieve water inside the column. The gauze prevents dirt from entering the water column and so protects the water sensor probes from contamination. There is an inherent risk of the water column gauze for water inlet to be blocked because of accumulation of dirt. It is therefore important that the water column is inspected and washed periodically to remove blockages that can hinder the inflow of water inside the column. Also, the four metallic probes need to be inspected and cleaned to keep them in good working conditions. The materials used for the invention of this device are resistant to corrosion. The water sensor metallic probes used are easily pluggable and replaceable during routine inspections. On the average, the metallic probes should be changed every two years. Emergency electric power supply is made available for the functioning of this device during power outage using a 12-V battery or power generators that runs on fuel or any economically viable electric power source within the locations. This is to recharge the battery of the invented device. Further validation of the performance of the invented device via real-time field-test on flood prone roads to actually track its capability for advance warning before commercial deployment is imperative.

4.2. Limitations of this study

The developed device only measures the flood level but does not detect the velocity of the flood. The major components of the flood hazard are the level of floodwater depth and also the velocity of the flood waves [31–33]. The capabilities of the developed product which detects the flood level can be enhanced in future to also monitor the velocity of the flood waves by introducing pressure transducers attached to the water column. The impact of the generated pressure by the flood waves will be amplified and transformed to electronic impulse which is calibrated to determine the flood velocity in meters per second. The existing water current meter available in the market that can be readily integrated into the device to achieve measurement of flood wave velocities is the Valeport model 803 ROV current meter. The development of an advanced model of this product in future will include its capability to measure flood velocity with additional cost.

The practical implication of this work is on developing adaptive technology to manage flooding of roads. The rise in sea level leading to flooding of the vehicular roads is a major concern in developing countries of Africa with poorly constructed roads causing huge economic losses. The existing technology of road flooding caution alarm devices malfunction on muddy, slurry, dirty water which damages the ultrasonic sensors. The developed cost effective and highly efficient road vehicle flood level monitoring device warns road users of flood level above a predetermined permissible threshold. The implication of the developed device is that road accidents associated with excessive road flooding is averted. Road users can now be aware of flooded roads on time to enable them follow alternative routes.

Resistivity of water is a measure of the ability of water to resist an electrical current. It is directly related to the amount of dissolved salts and other impurities in the water.

Flooding could be as a result of several factors, the most prominent ones being: Ocean Surge, River overflowing its banks, and Run-off during Heavy Rain-fall. The response of the device therefore may be affected indirectly by the cause of the road flooding. Table 5 shows a comparison of different water source resistivity/conductivity.

This implies that the invented device has a very high response rate. Accordingly, it is projected to be fastest with ocean surge and least with rainfalls. Moreover, the delay in response time in all cases is still less than 1 s which is highly insignificant with reference to the purpose for which the device is required.

The sensitivity of the metal probes depends on the resistivity of the material used which in this case is copper. The resistivity of copper is 1.72×10^{-8} Ωm. This translates to a conductivity of 5.8×10^{7} S. This is very high compared to that of water and therefore makes that of water insignificant. It is also important to note that the spacing of the probes would be just a few centimeters say between 5 cm and 25 cm depending on the determined user safety flood water level imputed to be detected.

5. Conclusion

An easily deployable simple and robust road flooding level monitoring device has been invented and implemented so as to address the challenges confronting the existing models of the device making it suitable for Africa. The effectiveness and efficiency of the invented device has been demonstrated through a field test. The invented device provides a solution to the menace which flooding poses on roads to the risk of motorists and other road users particularly in low economy societies of Africa. A cost comparison of the device prototype with an existing variant provides a cost advantage of about 25%. This establishes the fact that the invented device is also affordable and will compete favorably with other variants currently in the market.

This paper therefore proposes a mandatory inclusion of the invented device on all roads that are prone to flood hazards in Africa so as to provide users with the required advanced warning and also the implementation of its interoperability with Google map to realize

Table 5
Comparison of Water Resistivity/Conductivity (Values are at an average temperature of about 25 °C).

WATER	RESISTIVITY (Ωcm)	CONDUCTIVITY(Siemens)
Pure Water	20,000,000	5×10^{-8}
Distilled Water	500,000	0.000002
Rain Water	20,000	0.00005
Tap Water	1000–5000	0.001–0.0002
River Water	200	0.005
Sea Water	30	0.033

Source: Authors

its full potentials. In situations whereby there are no streetlights on the roads prone to flooding, metal pole supports can be used for the installation of the invented device. The electric power supply could be from solar panel power supply, fossil fuel power generator, or any economically viable electric power source within the location of target areas.

The invented device has been granted patent by the Federal Republic of Nigeria with registration number NG/P/2018/14.

Funding

This work was supported by University of Lagos Research Prototyping Funds.

Data availability statement

Data associated with this study are not publicly available. Data will be made available on request.

CRediT authorship contribution statement

Uzoma Ifeanyi Oduah: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Christopher M. Anierobi:** Formal analysis, Project administration, Resources, Writing – original draft, Writing – review & editing. **Olufemi G. Ilori:** Data curation, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] H. Alifu, Y. Hirabayashi, Y. Imada, et al., Enhancement of river flooding due to global warming, Sci. Rep. 12 (2022), 20687, https://doi.org/10.1038/s41598-022-25182-6.
[2] N. Wunderling, R. Winkelmann, J. Rockström, et al., Global warming overshoots increase risks of climate tipping cascades in a network model, Nat. Clim. Change (2022), https://doi.org/10.1038/s41558-022-01545-9.
[3] J. Terhaar, T.L. Frölicher, M.T. Aschwanden, et al., Adaptive emission reduction approach to reach any global warming target, Nat. Clim. Change 12 (2022) 1136–1142, https://doi.org/10.1038/s41558-022-01537-9.
[4] B. Jongman, P.J. Ward, J.C.H. Aerts, Global exposure to river and coastal flooding; Long term trends and changes, Global Environ. Change 22 (2012) 823–835.
[5] P. Peduzzi, H. Dao, C. Herold, F. Mouton, Assessing global exposure and vulnerability towards natural hazards; the Disaster Risk Index, Nat. Hazards Earth Syst. Sci. 9 (2009) 1149–1159.
[6] H. Chang, M. Lafrenz, I.W. Jung, M. Figliozzi, D. Platman, C. Pederson, Potential impacts of climate change on flood-induced travel disruptions: a case study of Portland, Oregon, USA, Ann. Assoc. Am. Geogr. 100 (4) (2010) 938–952.
[7] A.C. Pisor, X. Basurto, K.G. Douglass, et al., Effective climate change adaptation means supporting community autonomy, Nat. Clim. Change 12 (2022) 213–215, https://doi.org/10.1038/s41558-022-01303-x.
[8] A. Iloeje, C. Aniagolu, Impact of flooding on road transport infrastructure in Enugu metropolitan city, Nigeria, Int. J. Eng. Res. Afr. 5 (2015) 104–118.
[9] G.J. Schumann, G.R. Brakenridge, A.J. Kettner, R. Kashif, E. Niebuhr, Assisting flood disaster response with earth observation data and products: a critical assessment, Rem. Sens. 10 (2018) 1230, https://doi.org/10.3390/rs10081230.
[10] H. Wei, G. Zheng, V. Gayah, Z. Li, Recent advances in reinforcement learning for traffic signal control: a survey of models and evaluation, ACM SIGKDD Explor. Newsl. 22 (2021) 12–18.
[11] P. Milly, R. Wetherald, K. Dunne, T. Delworth, Increasing risk of great floods in a changing climate, Nature 415 (2002) 514–517.
[12] D. Jaroszweski, L. Chapman, J. Petts, Assessing the potential impact of climate change on transportation: the need for an interdisciplinary approach, J. Transport Geogr. 18 (2) (2010) 331–335.
[13] K. Pyatkova, A.S. Chen, S. Djordjevic, D. Butler, Z. Vojinovic, Y.A. Abebe, M. Hammond, Flood impacts on road transportation using microscopic traffic modeling technique, SUMO User Conf. (2015). http://hdl.handle.net/10871/21209.
[14] U.I. Oduah, G.W. Onokpite, O.S. Dairo, Development of an improved vehicle speed tracking device, FUW Trends Sci. Technol. J. 2 (1B) (2017) 350–354.
[15] C. Fischer, R. Gerstmeier, T.C. Wagner, Seasonal and temporal patterns of rainfall shape arthropod community composition and multi-trophic interactions in an arid environment, Sci. Rep. 12 (2022) 3742, https://doi.org/10.1038/s41598-022-07716-0.
[16] I. McCallum, et al., Technologies to support community flood disaster risk reduction, Int. J. Disaster Risk Sci. 7 (2016) 198–204.
[17] J.G. Natividad, J.M. Mendez, Flood monitoring and early warning system using ultrasonic sensor, IOP Conf. Ser. Mater. Sci. Eng. (2018) 325, 012020-012026.
[18] M. Mousa, X. Zhang, C. Claudel, Flash flood detection in urban cities using ultrasonic and infrared sensors, IEEE Sensor. J. 16 (19) (2016) 7204–7216.

[19] Y. Hirabayashi, S. Kanae, S. Emori, T. Oki, M. Kimoto, Global projections of changing risks of floods and droughts in a changing climate, Hydrol. Sci. J. 53 (4) (2008) 754–772.
[20] D.J. Parker, Flood warning systems and their performance, Nat. Hazard Sci. (2017), https://doi.org/10.1093/acrefore/9780199389407.013.84.
[21] H. Yuliandoko, A. Rohman, Flooding detection system based on water monitoring and ZigBee Mesh Protocol, 2019 4th Int. Conf. Inf. Technol. Inf. Syst. Electr. Eng. (ICITISEE) (2019) 385–390.
[22] A. Cataldo, E. Piuzzi, E. De-Benedetto, G. Cannazza, Experimental characterization and performance evaluation of flexible two-wire probes for TDR monitoring of liquid level, IEEE Trans. Instrum. Meas. 63 (12) (2014) 2779–2788.
[23] B. Jin, Z. Zhang, H. Zhang, Structure design and performance analysis of a coaxial cylindrical capacitive sensor for liquid-level measurement, Sensor. Actuator. A 223 (2015) 84–90.
[24] V. Milosavljevic, V. Mihajlovic, V. Rajs, M. Zivanov, Implementation of low cost liquid level sensor (LLS) using embedded system with integrated capacitive sensing module, Mediterr. Conf. Embed. Comput. (2012) 58–61.
[25] M.T. Tabada, M.E. Loretero, F.F. Lasta, Investigation on the performance of a multi-wire water level detection system using contact sensing for river water monitoring, SN Appl. Sci. 2 (2020) 77, https://doi.org/10.1007/s42452-019-1887-0.
[26] B. Shi, S. Catsamas, P. Kolotelo, M. Wang, A. Lintern, D. Jovanovic, P.M. Bach, A. Deletic, D.T. McCarthy, A low-cost water depth and electrical conductivity sensor for detecting inputs into urban stormwater networks, Sensors 21 (2021) 3056, https://doi.org/10.3390/s21093056.
[27] L. Areekath, G. Lodha, S.K. Sahana, B. George, L. Philip, S.C. Mukhopadhyay, Feasibility of a planar coil-based inductive-capacitive water level sensor with a quality-detection feature: an experimental study, 23, Sensors (Basel) 22 (15) (2022) 5508, https://doi.org/10.3390/s22155508. PMID: 35898013; PMCID: PMC9331053.
[28] M.S. Mukesh, Y.B. Katpatal, D.S. Londhe, Analyzing the impact of floods on vehicular mobility along urban road networks using the multiple centrality assessment approach, 01855871, ASCE-ASME J. Risk Uncert. Eng. Syst. Part A: Civ. Eng. 8 (2022) 3, 10.1061/AJRUA6.0001256.
[29] M.S. Mukesh, Y.B. Katpatal, D.S. Londhe, Measurement of city road network resilience in hazardous flood events, Int. J. Disaster Resilience Built Environ. (2022), https://doi.org/10.1108/IJDRBE-11-2021-0155.
[30] M.S. Mukesh, Y.B. Katpatal, Impact of the change in topography caused by road construction on the flood vulnerability of mobility on road networks in urban areas, ASCE-ASME J. Risk Uncert. Eng. Syst. Part A: Civ. Eng. 7 (2021) 3, https://doi.org/10.1061/AJRUA6.0001137.
[31] J. Du, J.S. Kimball, J. Sheffield, M. Pan, C.K. Fisher, H.E. Beck, E.F. Wood, Satellite flood inundation assessment and forecast using SMAP and landsat, IEEE J. Sel. Top. Appl. Earth Obs. Rem. Sens. 14 (2021) 6707–6715, https://doi.org/10.1109/JSTARS.2021.3092340 [PMC free article] [PubMed] [CrossRef] [Google Scholar].
[32] H.S. Munawar, A.W.A. Hammad, S.T. Waller, Remote sensing methods for flood prediction: a review, Sensors (Basel) 26–22 (3) (2022) 960, https://doi.org/10.3390/s22030960. PMID: 35161706; PMCID: PMC8838435.
[33] I. Ahmad, X. Wang, M. Waseem, M. Zaman, F. Aziz, R.Z.N. Khan, M. Ashraf, Flood management, characterization and vulnerability analysis using an integrated RS-GIS and 2D hydrodynamic modelling approach: the case of Deg Nullah, Pakistan, Rem. Sens. 14 (9) (2022) 2138, https://doi.org/10.3390/rs14092138.