NovoVerse Undergraduate eJournal

Volume 1 · Issue 1 · June 2018

Exploring the Potential for Cost-Saving Technologies in Alleviating the Consequences of Hydro-Meteorological Hazards in Ireland

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Abstract

The impact that floods are having on our economic and social climate is an ever-increasing problem due to the effects of climate change. Thus, identifying low-cost solutions to this problem using newly-created technology has become a very relevant research area. Flood monitoring has always been a popular area of research however the contemporary monitoring systems in place are costly and thus alternatives and improvements to these are explored. Investigation into current procedures and sensors in place in Ireland is carried out and viable, innovative solutions are identified. Solutions are identified for improving energy-expenditure and reducing maintenance work needed for these new sensors versus the present systems. Investigations into the benefits and possibilities provided by the LoRa network are also accomplished. Finally, problems with the current state of insurance for flood prone properties are identified and explorations into the use of blockchain technologies to address this situation and alleviate the consequences of flooding are also explored

Keywords: *Flooding, Internet of Things Sensors, LoRa, Open Data, Blockchain*

1. Introduction

A destructive yet unfortunately, very common issue in Ireland is the regular flooding that it experiences. At the start of 2018, images and videos surfaced on news and media sites depicting the all too familiar scene of rivers across Ireland breaking their banks and flooding the surrounding areas. Unfortunately, these areas are often densely populated with restaurants, coffee-shops, stores, hotels and homes. Often, these floods are unprecedented, and no sufficient prior warning can be given to the businesses or homeowners in the affected areas. Considering the synonymous relationship between Ireland and rain it can also sometimes be difficult to predict when heavy rainfall can turn into a devastating flood.

However, as devastating as these floods can be, sometimes it is just not worth it for the Government to invest in an expensive and often un-aesthetic flood protection system. Sometimes locals just prefer an unadulterated view of the sea or the river no matter the damage caused by a flood. In the case of Clontarf, Dublin, local drivers complained about a newly built sea wall due to their inability to see the scenery while driving. As of January, the County Council overwhelmingly voted for the lowering of the wall by 30cm, an initiative that will cost the Council upwards of €500,000. (Kelly, 2018)

In the case of Galway City, situated in Ireland's infamously rainy West Coast, some 890 properties are at high risk of regular flooding. However, it has been estimated that any possible damage caused by the flooding will never exceed the costs of implementing a €9.5M flood defence system (Melia, 2018). Many other at-risk Irish areas have also been overlooked by the Government for the implementation of flood defences on economic grounds. The main problem with this is that insurance companies refuse to provide flooding cover for these areas unless protection systems are in place, leaving many home and business owners fearing the financial impact of the next major bout of rainfall. Unfortunately, it seems that the harsh reality for many Irish Citizens is that their Government believe that protecting their businesses and homes is not worth the cost and they should be left to deal with it themselves.

It is true, to put a flood protection in place would be extremely expensive. However, there are other, less expensive ways to improve upon this situation. Rather than investigate new ways of protecting against floods when they inevitably occur, the Government should be looking towards predicting when and where these floods are going to happen and protecting and informing their Citizens based on these predictions. This study identifies the possibility of obtaining these predictions through the collection and analysis of real-time datasets gained from the implementation of a system of low-cost IoT sensors. This research paper theorises that by implementing a system like this Governments and Citizens can gain important insights into real-time local water conditions and obtain valuable time to create defences and inform citizens if needs be.

Therefore, this investigation intends to explore this possibility with the ultimate goals of:

a) Identifying low-cost, low-maintenance and low-energy IoT technologies that carry much potential for flooding prediction.

b) Outlining methods of providing citizens with accurate and timely flood related information.

c) Reducing costs associated with flooding.

2. Theoretical Underpinning

How data is collected, visualised and analysed has changed massively over time, from the ancient Lascaux cave paintings depicting an improved way to hunt deer to ultra-modern data-centres and dashboards. However, this change and the greater contemporary technological era that it is part of could never have been achieved without a drive to improve upon and innovate current processes. Few other contemporary technological areas are as deeply innovative as the development of the IoT. This development mostly outlines the identification of processes, such as rainfall or stream gauging, in which IoT technologies can be usefully applied to innovate this process. This has brought about many big changes surrounding data collection and how to utilise this data. Since cheap IoT technologies can be easily acquired, many IoT developers have opted to publicly release the code behind various applications and urged other users to develop and improve upon them. This open source nature has led to the forming of an advanced and highly-innovative community consisting of developers, inventors and data scientists to name but a few. This community are dedicated to finding new ways to help with old problems. A large focus for many of these members has been to create low-cost, low-energy and low maintenance sensors yet also maintain the reliability and accuracy of the previous methods. This has led to the emergence of a number of extremely low-cost technologies that can be applied in many areas.

Since hydro-meteorological issues such as flooding is a destructive issue both nationally and internationally this study identifies the possibility for some of these low-cost technologies to be implemented to help alleviate some of the issues associated with it. It is proposed that the technologies and instruments currently used to measure the 3 crucial datasets involved in flood management: water level, stream velocity and rainfall levels, carry much potential for improvement in the areas of maintenance, cost and energy efficiency. This improvement can one day be achieved by the testing and appropriate implementation of low-cost IoT technologies like those identified later in this paper. Eventually, total replacement of current systems by the more efficient technologies could even be considered.

For rainfall data, high cost systems such as the Casella tipping bucket rain-gauge currently in place in Dublin are favoured for flood prediction. These sensors must be constantly connected to a power source and transmit data over a private cellular band thus incurring a maintenance cost per month. Newer sensing methods will be explored that carry potential to improve upon these downsides.

To collect water level data, flotation devices are widely used. These devices are often housed in protective plastic or steel casing and attached upright to piers or bridges are also in use. Unfortunately, these floats can be expensive to implement and are often only placed out during periods when flooding is a serious danger to lives, like when the US Geological Survey set up a system of 60 storm tide sensors in anticipation for Storm Nate in late 2017. Various lower-cost, alternative options are explored that carry potential to improve upon these current sensors.

Since stream velocity is the most difficult dataset to collect using technology, it is often carried out using expensive, handheld windmill like devices that are submerged in the water. A reading is taken based on the speed that the windmill turns. Exploration of recent technologies and studies has led to the identification of potential ways this can be improved upon.

Blockchain was originally developed as the accounting method for virtual currencies such as Bitcoin, which use distributed ledger technology (DLT)(Pinna and Ruttenburg). These technologies are appearing in a multitude of commercial applications today and are not just limited to the crypto currency market. The technology is currently used primarily to verify transactions within digital currencies though it is possible to digitize and insert a variety of different documents into the blockchain. In doing this, an indelible record is created that cannot be changed or tampered with, moreover the record's authenticity can be verified by the entire community using the blockchain instead of a single authority (McKinzey 2016). In realising the potential for blockchain to be used as not only a ledger for insurance companies to ensure that all assets are accounted for to calculate proper premiums and issue fair claims when flooding does strike but also as a method for the government to keep track of citizens when disaster does strike.

3. Methodology

The purpose of this paper's research is to explore the potential for cost-saving technologies in alleviating the consequences of flooding in Ireland. To gain a broader understanding of the problem, a multi method research approach was carried out in this study. While there is a modest amount of empirical research obtainable online, an exploratory approach was taken to gather the profusion of relevant information required. An archival research approach was also taken in exploring various studies, however, to develop a further insight into how cities with smart flood sensor operations in place operate, a case study on Smart Dublin and the system they currently have in place was developed. Through a combination of online content analysis and a half hour, unrecorded, questionnaire based interview with a project manager involved in the Smart Dublin initiative the case study was developed. For the analysis of this research paper to remain relevant to an Irish perspective, a focus on Dublin was put in place when conducting the case study as it operates under similar governance which would allow homogeneous operations to be carried out elsewhere in the country. The investigation into smart flood sensor management in Dublin took place between November 2017 and March 2018 and focused on creating cost benefit analysis of the sensors and other flooding alleviation methods as well as what can be applied to other cities.

4. Findings and Discussion

4.1 Sensors

Research suggests that there is a very real potential to use a low-cost, low-maintenance and low- energy sensor system for flooding prediction in Cities across the world.

This potential revolves around a key-tool in the rise of low-cost yet innovative IoT solutions for Smart Cities called LoRa. LoRa, short for Long Range, is a Low-Powered Wide Area Network that has been promoted specifically for the IoT by a non-profit organisation called the LoRa Alliance and developed by Semtech.

The LoRa network carries with it many benefits for IoT projects. Firstly, it is an unlicensed band. This means that anyone can set up a system of devices on the LoRa network can do so without charge (Augustin et al, 2016). Secondly, communication using the LoRa network provides broadcasting range that can be wider than existing cellular networks, with rural communication ranging up to 30 Miles in some cases. However, this is only achievable with line-of-sight communication and research suggests that, for urban implementation, a range of 2-10km is recommended to ensure most packets transmit successfully (Petajajarvi, J. et al, 2015). Thirdly, LoRa is designed for very low power consumption. Considering the miniscule size of the data that needs to be transmitted via these sensors, the network does not need to be high-powered to do its job. Lastly, LoRa is secured with end-to-end encryption making it a very secure option (LoRa Alliance, 2016). These benefits make the LoRa network particularly well suited for projects focused on low-power and low-cost options without sacrificing range (Augustin et al, 2016).

Because of these vast benefits, LoRa plays a crucial part in the operation of many smart projects including in the case of Dublin City Council and CONNECT's rainfall sensor program. It was through communication with CONNECT and the development of the Dublin case study that the pivotal role the LoRa network plays in low-cost IoT innovation was identified.

LoRa has the potential to solve many of the problems that we see with older, more expensive weather monitoring systems. A new system does not have to use the expensive licensed network band or existing wi-fi networks for data transmission. This means that it does not require constant connection to a fixed power source and therefore enables it to run for a very long time from standard batteries.

As well as LoRa, the other crucial element of a system like this is the transceiver: a combination of a Microcontroller, the LoRa Radio Module, an antenna and a battery pack all housed in a protective, waterproof container. In most documented cases, an Arduino Pro-Mini has been used as the Microcontroller (Noraini Azmi et al, 2018) which is then configured for use with a various LoRa enabled radio module. Additionally, due to the open-source nature of LoRa, many developers have come up with ways to enable the transceiver to run on extremely low-power and utilise the full potential of the network. Congduc Pham of the University of Pau documented a step-by-step guide for creating a 3.3V transceiver that only powers on when taking a reading, (*Pham, C. 2016)* thus allowing it to expend only a small portion of the energy as it would if it was constantly on. His reports on GitHub claim that a system like this can run on 4 AA batteries for over a year when taking one reading every ten minutes and for several years when taking one reading every hour (*Pham, C, 2017a)*. He also documented how to configure the device for outdoor use (*Pham, C, 2017b)*. A transceiver like this can be created at an extremely low-cost, with calculations coming to about €25 in total.

When it comes to flooding data, three datasets have been identified that, when collected and analysed conjunctively, carry potential to provide extremely reliable insights into the movement of bodies of water in the area and, as we theorise, predict the exact nature of a flood. These datasets are rainfall, water level and water velocity.

4.1.1 Rainfall

As flooding is predominately caused by inordinately high levels of rainfall, the rainfall dataset is deemed to be the most vital component to measure when it comes to flooding. It is also the most straightforward. Valuable insights into these sensors were gained through analysis of CONNECT and Smart Dublin's flooding initiative (Doyle, 2017). Dublin's current rainfall monitoring system, like many other cities globally, uses tipping bucket rain-gauge (TBR) sensors that transmit the data through a private cellular band. Each sensor requires constant connection to a power source and to be 'topped up' with credit each month to continue using the internet. From these obvious drawbacks of the older system, potential for a much cheaper system was identified. This battery-powered system features a low-cost TBR connected to a transceiver that transmits collected data over the LoRa network. CONNECT are currently in the process of testing this new system for accuracy against the older one but preliminary results are promising. Research has shown that TBRs, when set up correctly, carry a residual error less than ± 1% (G. Lanza and Stagi, n.d.) . However, the accuracy of these low cost TBRs has not been overly investigated but we are hopeful that CONNECT's initiative will provide some valuable insights in the future.

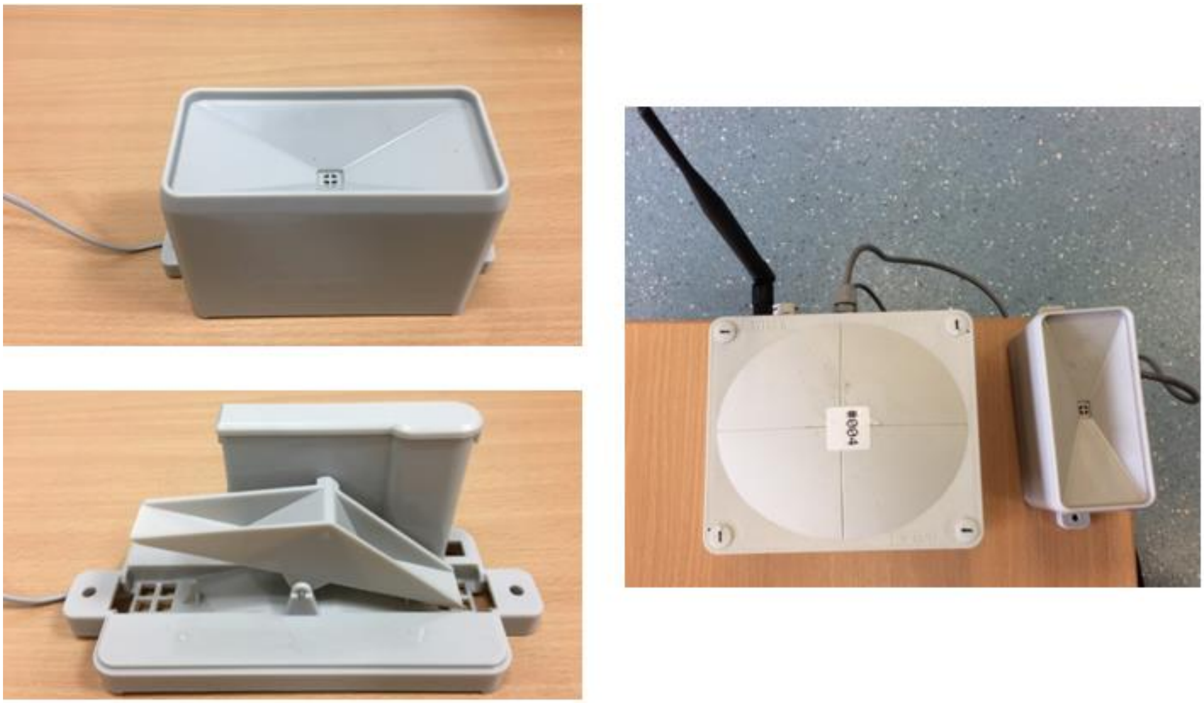
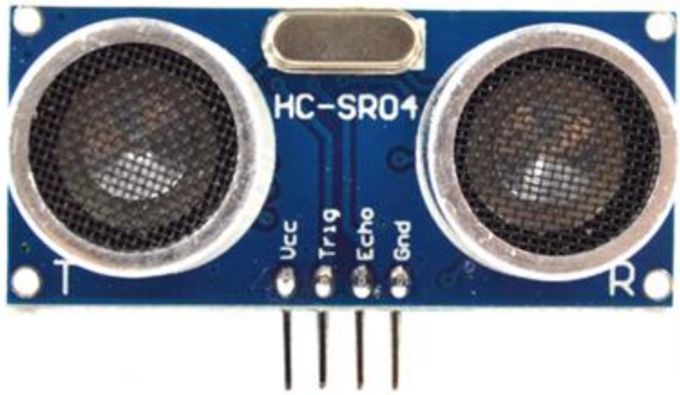


Figure 1: Low-Cost Tipping Bucket Rain-Gauge (TBR) Complete with Transceiver (Right)

4.1.2 Water Level

The measuring of water level is slightly trickier. Many different types of sensors have been successfully tested for this task in a controlled, indoor environment, from Infrared Sensors (Priya and Chekuri, 2017) to Liquid Level Sensors (Kanth, 2017) yet neither suit the altogether more difficult task of monitoring water levels in an outdoor, free-flowing system of water like a river or a canal. However, there have been multiple studies and tests done where ultrasonic sensors like the HC-SR04 have been successfully implemented to test water levels in free-flowing bodies. They are very low-cost, transmit data quickly and can easily be configured to work with a MicroController. They carry potential advantages over more traditional methods because of this (Kato, Sinde and Kaijage, 2015). The HC-SR04 has been found to carry a 96.6% average accuracy for water level measuring (Nasution et al., 2018) but, while this is well within the scope of accuracy for flood detection, unfortunately there are a few disadvantages too. Firstly, they are very difficult to waterproof. Any complete waterproofing measures seem to interrupt the ultrasonic measuring system. This means that they are not suitable for placement in areas where splashing from waves is a danger. However, they can easily be made rainproof by placing them in protective containers. Fortunately, they can easily be attached to the underneath of bridges too. Floating debris also can cause multiple errors in calculation (Nasution et al., 2018) however the errors are generally minor and short-lasting due to the nature of moving debris.



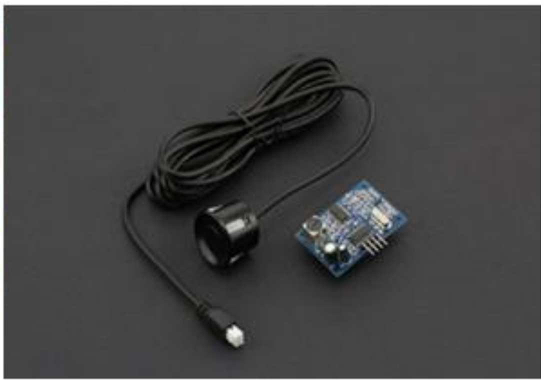


Figure 2:HC-SR04 Ultrasonic Sensor (left) and Waterproof Ultrasonic Sensor (right)

Some promising additional research has been carried out regarding the use of low-cost waterproof ultrasonic sensors for measuring water level in irrigation farming techniques (Yaswanth Sai, 2017). Some additional research needs to be done on these sensors before we can see them being implemented for flood detection but, if they are proven to be accurate, they will be more suited to the task than the HC-SR04.

4.1.3 Water Velocity

The measuring of river velocity, also called stream gauging, is the most difficult of the 3 datasets to collect. Free flowing waterways are, by nature, unpredictable and ever-changing. The multiple limitations imposed by this unpredictable nature such as transported debris and variable river depth has led to the task of river-gauging being described by IS professionals as intrinsically complex (Ancona et al., 2015).

Due to the difficult nature of stream gauging, many interesting research angles have been taken in the search for the best way to complete the task including in the category of non-contact sensors. Perhaps the most promising advances have been made in the field of Large-Scale Particle Image Velocimetry (LSPIV), where imaging-based systems are deployed to estimate the distribution of surface velocities by tracking patterns on the surface of the water (Ran et al., 2016). Imaginative, yet expensive measures such as integrating LSPIV and Unmanned Aerial Systems (UAS) (W.Lewis and L.Rhoads, 2018) and Drones (Tauro, Petroselli and Arcangeletti, 2015) have been investigated with good results. Low cost and low energy LPSIV methods using a Camera and a Raspberry Pi have also shown promise (Ran et al., 2016). However, due to the energy expenditure and large data size associated with image/video recording, LPSIV methods cannot easily transmit the data for quick analysis without deeply impacting the battery life of the system.

The use of low-cost, submerged flow sensors however, carries its own disadvantages. The sensor itself is generally composed of a pipe-like system with a windmill in the middle of the pipe. The faster the windmill flows the stronger velocity is recorded. They are low-cost, can run on low-energy (Nasution et al., 2018) and can easily be programmed to work with the LoRa transceiver. Current research carried out on these sensors has been limited but promising, ranging from testing the sensors in miniature-systems (IFEDAPO ABDULLAHI et al., 2017) to slow-flowing rivers (Nasution et al., 2018). This research does point to their suitability for use in slower-flowing waterways like canals. Unfortunately, there is no evidence that they would last for long in a fast-flowing river like that of the Corrib in Galway City. Logically speaking, flowing debris may damage the device or at least create a cohort of errors in the data. It is theorised, however, that if a stable, protected container with a mesh face was created for the device, it may well improve upon this disadvantage. Additional research needs to be carried out on this.

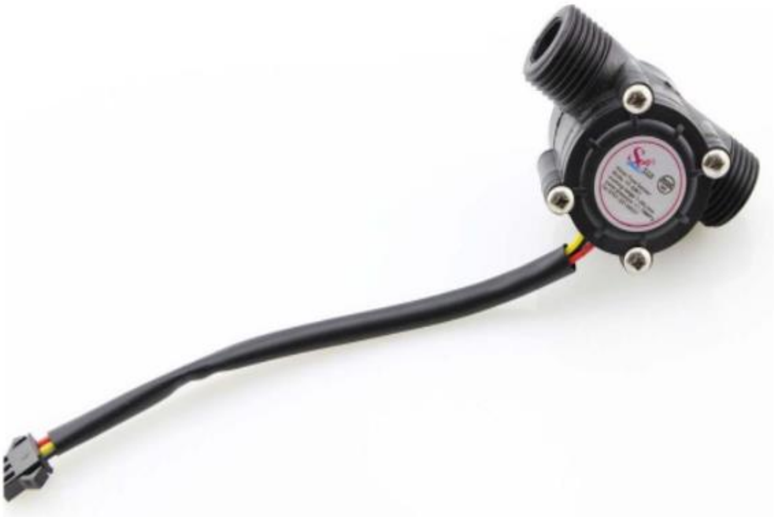


Figure 3: Low-Cost Water Flow Sensor

4.2 Alerting people of the problem.

A city could have one of the most advanced and efficient flood protection systems in the world, but if the city's people are not alerted when there is an incoming flood threat, then this renders much of the equipment un-necessary. Citizens receiving a flood warning in sufficient time is one of the keys to being prepared. Giving people a flood warning in the necessary time allows them to erect their sand bag barriers or any other flood protection measures that are required.

As the real-time data is being collected from the sensors, the data can be monitored by an early warning system. (EWS) This system is programmed to predict a flood based on the data that is being fed from the relevant sensors. Once a flood is predicted, an alert can be sent to the relevant experts to verify the threat before the alert is sent out to the public.

If the data shows that a flood is likely to take place, an alert is generated automatically which can then be updated. The communication of the warning itself is the significant step between the actual forecasting and the resulting actions. (Cools, Innocenti and O'Brien, 2016) To be used to trigger response actions, warnings need to be trusted, understood and useable (Mayhorn and McLaughlin, 2014) The information communicated to the people on the app will show the predicted extent of the flood and a colour coded scale of the predicted flood on a map. For each alert level, a different colour will be used, green, yellow, orange and red. (Cools, Innocenti and O'Brien, 2016) This will give people an accurate picture of the strength of the flood to allow them to prepare accordingly.

Along with alerting the general population of the city, an early warning flood alert system will allow the necessary committees to meet such as the emergency department, the local fire brigades and the local and regional authorities. This will give these authorities more time to devise a plan to combat the flood. Furthermore, the data and experience gained through the early warning system can be used to model future flood detection systems. (Cools, Innocenti and O'Brien, 2016)

The flood warning alert can be sent out through text message and through a notification on an app. As most people have a smart phone at present, an app would reach most of the target market however the remainder will be accessible through a text message. Open Data collected by the flood sensors could also be made available through an app. This would allow people to see what the flood risk levels are at all times and allow developers to utilize the data for other beneficial purposes. The data could also be made available in an Open Data portal as well as the app.

4.3 Fixing the Damage

An advanced flood prediction system can provide many benefits but, unfortunately, floods will continue to cause catastrophic damage for communities worldwide. A big issue for Irish properties at risk of flooding is the fact that obtaining flooding insurance for these properties is generally not possible. It simply makes no sense from the insurance companies' point of view to provide cover for damage that will undoubtedly occur. A possible way has been identified that, by using Blockchain technologies, insurance companies will be better able to provide coverage for these vulnerable households. By putting all of the items in a flood prone house on the Blockchain insurance companies can consistently update the value content for individual homes and adjust premiums accordingly at any given point of the year. This also enables them to only remove coverage during flood seasons, thus allowing households to have coverage for robbery or fire when they otherwise would have been rejected for all insurance claims based on their location.

Both the insurance company and its customers are facing issues that Blockchain and smart contracts could solve. Insured individuals often find the contracts to be long and confusing whilst companies are battling an ever-increasing amount of fraud. By using Blockchain and issuing smart contracts, both the companies and individuals would benefit from managing claims in a transparent way. To accomplish this, contracts would be recorded and verified on the Blockchain. When a claim is submitted it would initially be either verified or rejected by the Blockchain, ensuring only valid claims receive compensation. This removes the need for human intervention in small and easy to solve claims thus improving efficiency and possibly the overall rate of insurance. By gathering and processing the data with blockchain and correlating it with the data gathered from the sensors, more efficient and effective flood defensive measures can be put in place to ensure those most at risk are properly protected. Through this, future damage from flooding can be offset and or negated in its entirety. By gathering and processing the data with blockchain such as where the largest amount of insurance claims originates from and correlating it with the data gathered from the sensors proper measures can be taken to ensure that those most at risk are properly protected. This way costs are also saved as money isn't wasted on building flood defences in areas which may be flooded but are not occupied and have little to no claims stemming from them.

By making the data open the above positive impacts can be achieved easily. Trust will easily be established by allowing the public to have access to the data. Furthermore, efficiencies will also be achieved due to customers being more inclined to use Blockchain services because of their privacy features. Moreover, by allowing the public access to data on the contracts, with the private data of customers encrypted, it will entice new customers to apply for insurance given the ease of use with the smart contracts. Finally, by releasing data to the public on fraud and patterns companies will be better able to understand their customers, if average people are able to see how fraud is spotted they can assist in reporting it to the insurance companies, thus lowering their premiums. Moreover, by allowing the public to see where proper measures have been undertaken along with the sensors to alleviate and ensure damage is kept to a minimum, people will be more inclined to locate in these now safer areas as opposed to more flood prone locations.

Furthermore, another use for Blockchain in flood prone areas would be to store citizen's data and in the event of extreme flooding the Blockchain could independently verify with citizens via text or other forms of communication on their safety. This could also be used by the emergency services to ensure that all the residents of a given area are accounted for and safe. The main drawback with blockchain is the increasing energy costs as an ever-increasing number of nodes are mined to verify previous ones, thus costs expand exponentially. A possible workaround which is ideal for communication between devices is adopting Tangle. Tangle is the technology used to power the IOTA crypto currency, the difference between IOTA and other blockchain centred coins is that Tangle verifies a transaction by pairing it against other transaction ensuring that there are no costs and energy costs are kept much lower than traditional blockchain technologies (IOTA Whitepaper, 2017). Furthermore, Tangle also allows devices to communicate independently with each other without human interaction, further reducing costs. The only cost associated with the devices communicating with each other would be the purchase of IOTA tokens to access the Tangle framework, which are negligible when put in comparison to costs associated with maintaining a fully functioning blockchain framework.

Not only are individual homes affected by flooding, but it can also bring upon a huge financial burden to local communities and community driven organisations within cities, and it is often the communities themselves that are left with the problem of fixing it. It is often necessary that fundraisers to repair or renovate areas in which floods have been severely damaged must be carried out to combat this. From research, based on surveys by “Amarách Research”, just under half (44%) of Irish people trust their government (Ryan, 2018) and only 7% of people trust charities, rising to 29% including people who somewhat trust charities. (Charities Institute Ireland, 2017) In addition to these figures over half (54%) of people feel they do not know what charities do with the money donated and 74% of people feel that there is not currently satisfactory transparency to the operations of a charity. This can have a large effect on the management of flood damage fundraising as, while people want to donate to the cause, they’re not sure if their money is being put to good use. This is where blockchain carries the potential to be extremely useful. It allows for a transparent crowd funding platform to be created where donors can see on the blockchain when and for what their money is being used.

A social impact network as such in the form of “Alice” would be a resolution to this trust issue. In line with Alice, a platform based on the Ethereum Blockchain would be effective in creating transparency and trust between donors and fundraising projects as smart contracts would be in effect. Smart contracts are code written into the blockchain that executes once an event is triggered, in this case the completion of a task or confirmation of a goal. Initially donor’s payments would only be given to the project being carried out once a clearly defined set of goals are made and assigned validators validate these. In the case of local flood repair and restoration projects the validators would ideally be the local government. The confirmation of goals is a beginning necessity in creating this platform as to carry out the projects funding is required. However, it is not the final solution. To ensure complete trust in the projects carried out, it will be necessary for the money to be transferred from the donors once the goals are completed and not solely validated. In this scenario it is important for impact investors to be involved in the process as they provide the initial capital to fund the projects. The impact investor’s investments would be transferred to the project funds once the goals are validated and would be reimbursed by the donors once the projects are completed. Impact investors are vital in creating public trust in donations as they allow the public to track their donations and see exactly what they are used for in the blockchain. They seek to achieve a combination of financial return and social value return and with the crowd funding market reaching $2.56 billion worldwide in 2015, while only increasing since, they will provide the basis of a transparent blockchain fundraising platform that can be used to effectively repair and renovate damaged areas. (Thegiin.org. 2018).

The use of blockchain in both social and government areas will allow for a level of efficiency to be achieved not only in prevention but also in fixing the problem. This will allow for a decrease in overall costs ensuring that when problems do arise there is ample resources and funding available to accommodate them.

5 Implications for Theory and Practice

The objective of this study was to conduct an exploratory investigation into how low-cost IoT sensors can help alleviate Hydro-Meteorological problems in Irish cities. Both theoretical and practice contributions stem from this research. From a theory perspective in the past, vast research in flood defence has resulted in expensive infrastructure being recommended as the solution. This study explores research which proves flood prediction can be possible in a low cost, efficient manner. Furthermore, this study can be considered revelatory in that this study proves flood prediction does not require an extravagant amount of money to be invested. From a practise perspective, our study suggests local Government should invest in low-cost sensors to alleviate flooding problems in their area. While the sensors alone do not act as a prevention method for flood damage entirely, the data collected from sensors and insurance claims with blockchain technology can identify the most damage prone areas leading to efficient, targeted flood protection defences. This would be in favour of both the government – low cost, and the locals – aesthetics remain untouched. This study is naturally limited in terms of comparative studies as the findings have not been implemented currently in other cities. However, a substantial amount of consideration was taken in researching the methods proposed as a valid low-cost option for flood prediction and relating these methods as theoretical concepts. Given that the concepts in this study are largely untried, others will essentially need to test these methods and build further theory. Moreover, further research could be undertaken as an outcome of these studies in the areas of flood protection as a result of predicting a flood. With the proposed devices allowing more time for flood protection, there is vast room for research in what is the most efficient use of time between the flood being predicted and when the flood arrives.

Acknowledgement

The authors gratefully acknowledge Michael Guerin, CONNECT who provided us with valuable insights into flood sensors and the LoRa network.

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