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Smart Intelligent Predictive Real-Time Stormwater Management Monitoring (SISWM^2)

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ABSTRACT : *The smart intelligent predictive real-time stormwater management monitoring (SISWM^2) is the remote sensors' main advantage that automatically recognize and detect rising water levels and send early flood warnings to residents. The study was conducted to evaluate the effect of integrating sensors to green infrastructure (GI) to mitigate stormwater rising in the municipalities. Stormwater runoff from infrastructures needs monitoring because of its associated risks, including habitat degradation and river siltation. Early warning system for flash flood management caused by rapid rising stormwater functions mainly to alert people early of the risk of potential flooding. There is a need for technological advances to protect human lives and properties, hence the reason for the flood prediction sensor network in different communities.*

KEYWORDS: *Stormwater events; sensors networks prediction; flood mitigation strategies; green infrastructure.*

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I. INTRODUCTION

Every year in the United States, flash flooding causes tens to hundreds to thousands of deaths. According to the National Weather Service, there were 8307 flash flood fatalities from 1940 to 2020. In 2015, flash flooding led to 187 deaths; there were 92 flash flood fatalities in 2019; specifically, even with the pandemic, there were 57 flash flood fatalities in 2020. The fatalities are due to drowning when people walk in floods or vehicles in stormwater loss control. A predictive real-time stormwater monitoring is needed to adequately combat the challenges caused by climate change and urbanization in modern society. The development of an adaptive cost-effective predictive system will sufficiently boost rapid response for resourceful human health investment. Urban flood runoff has debilitating environmental health effects from pollution and economic impact, which caused loss of properties that cost about $3.75 billion in 2019 across the U.S. It affects the economy, people, and environment with significant impacts, including injuries and infrastructural damages.

Also, incorporating a stationary stormwater infrastructure system with adaptive real-time monitoring will yield enormous environmental protections. Rapid urbanization leads to many impervious surfaces that cause inundation during torrential rains, impairs sustainable flood management. Land use significantly increased construction activities due to rapid population growth, mostly in urban geographical regions of the world, resulting in altered ecosystems and disrupting the natural hydrologic cycle [1]. Impervious surfaces imposed greater demand on societies since there is reduced evapotranspiration and infiltration in most urban places [28][17][24][9]

Additionally, the aging gray infrastructures significantly contributed to the problems posed by today's climate changes due to reduced drainage caused by clogging drains during rising floodwaters. Flood occurs in most geographical locations of the world, and due to climate change, it can occur at any season of the year. Most low-lying landscape areas and rivers' locations are prone to flooding when torrential rainfalls [30][5].

Early warning system for flash flood management caused by rapid rising stormwater functions mainly to alert people early of the risk of potential flooding. This research will be for a low-cost, simple sensor to determine the water levels, and the data obtained will be utilized in evaluating flood risk assessment. The primary purpose of this study is to develop sensors that will detect water levels early and thereby alert residents of potential dangers. Preventing people from the potential risk of flooding [18] by sending out warning signals;

since stormwater from rain is a natural event. There is a need for technological advances to protect human lives and properties, hence the reason for the flood prediction sensor network installed in different communities. Collecting high amounts of spatial resolution dimensions data using an intelligent stormwater prediction system will provide better alert networks. The flood project is a resilient method to construction designs through low-cost sensors that function effectively with either gray or green infrastructures through the use of a predictive sensing system.

II. Estimation damage of stormwater management in the United States from 1980 to 2021

A. Billion-dollar events to affect the United States from 1980 to 2021

Disaster type	Events	Events/ Year	Percent Frequency	Total Costs	Percent of Total Costs	Cost/ Event	Cost/ Year	Deaths	Deaths/ Year
drought	29	0.7	9.40%	$285.48	13.20%	$9.8B	$6,8B	4,139	99
flooding	35	0.8	11.30%	$164.2B	7.60%	$4.7B	$3.9B	624	15
freeze	9	0.2	2.90%	$32.8B	1.50%	$3.6B	$0.8B	162	4
Severe storm	143	3.4	46.10%	$330.7B	15.30%	$2.3B	$7.9B	1880	45
Tropical cyclone	56	1.3	18.10%	$1,148.0B	53.20%	$20.5B	$27.3B	6,697	159
wildfire	19	0.5	6.10%	$120.2B	5.60%	$6.3B	$2.9B	401	10
Winter storm	19	0.5	6.10%	$78.6B	3.60%	$4.1B	$1.9B	1,277	30
All Disasters	310	7.4	100.00%	$2,159.9B	100.00%	$7.0B	$51.4B	15,180	361

Table 1: source: [31]

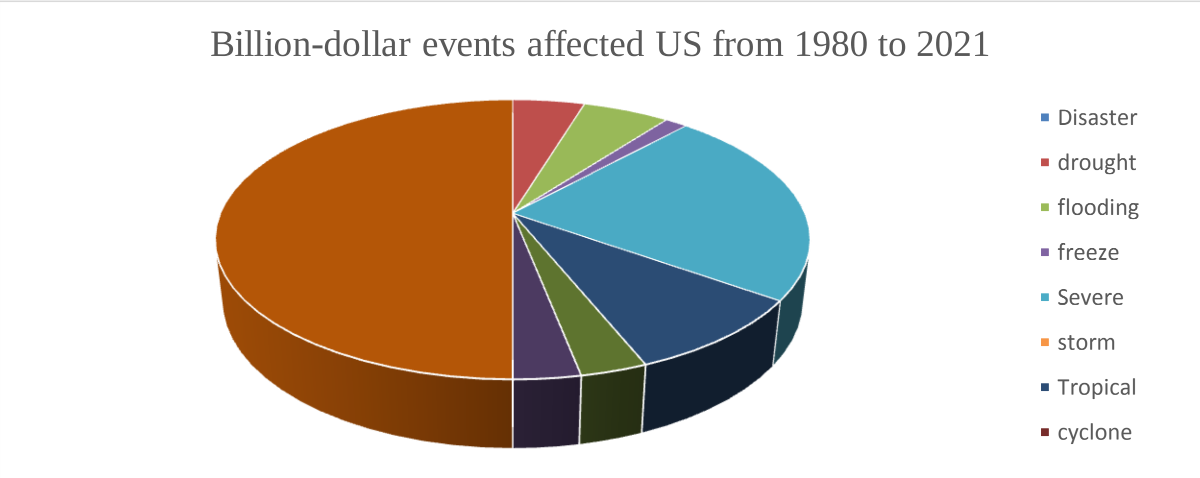

Figure 1

B. Time Period Comparisons of United States Billion-Dollar Drought, Freeze, Severe Storm, Tropical Cyclone, Wildfire, and Winter Storm Statistics

Time Period	Billion Dollar Disasters	Events/ Year	Cost	Percent of Total Cost	Cost/Year	Death	Deaths/Year
1980s (1980-1989)	25	2.5	$175.2B	8.8%	$17.5B	2,706	271
1990s (1990-1999)	45	4.5	$228.3B	11.4%	$22.8B	2,851	285
2000s (2000-2009)	60	6.0	$540.1B	27.1%	$54.0B	3,044	304
2010s (2010-2019)	105	10.5	$807.7B	40.5%	$80.8B	5,012	501
Last 5 Years (2017-2021)	79	15.8	$714.2B	35.8%	$142.8B	4,475	895
Last 3 Years (2019-2021)	51	17.0	$271.6B	13.6%	$90.5B	975	325

Last Year (2021)	18	18.0	$142.4B	7.1%	$142.4B	681	681
All Years (1980-2021)	275	6.5	$1,995.7B	100.0%	$47.5B	14,556	347

Table 2: source: [31]

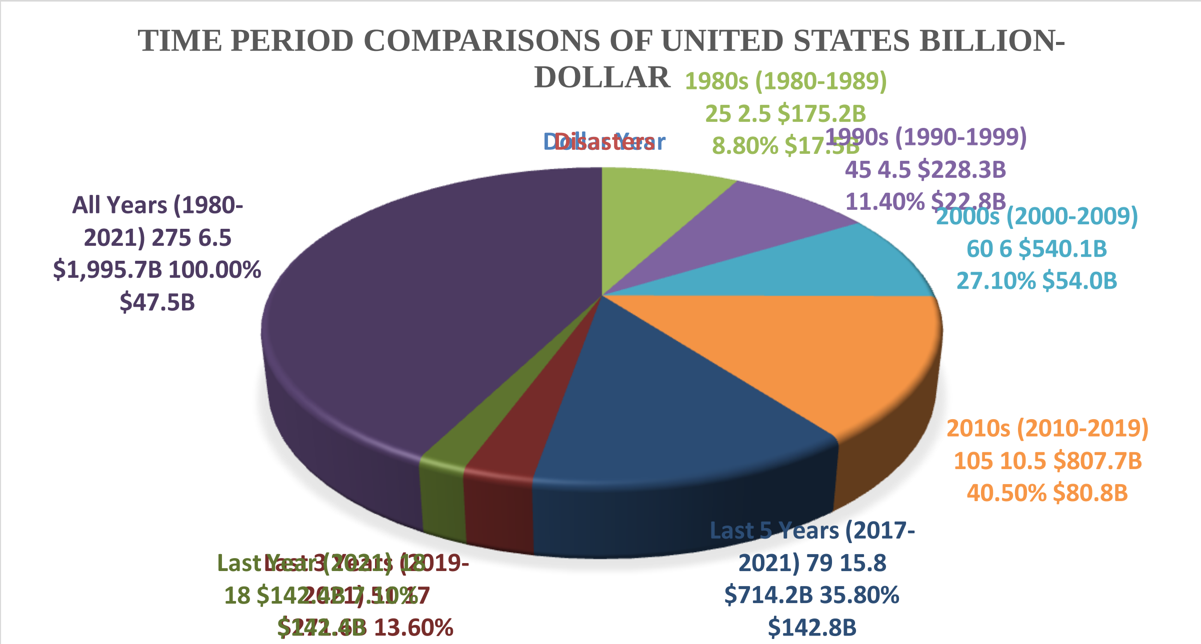

Figure 2.

III. Prediction of Rainwater using Weather Map in Python

First, create an account and sign in on Openweathermap.org and click on API tab, under current weather data, click API doc and go to API call and follow the steps to generate an API key. Second, download Python, install Pyowm, (Python Open Weather Map API) and copy API key from open weather map and paste into python 3.9.6 version. From Python, make an import request to get current weather data for a particular location.

A. SISWM^2 Architecture network

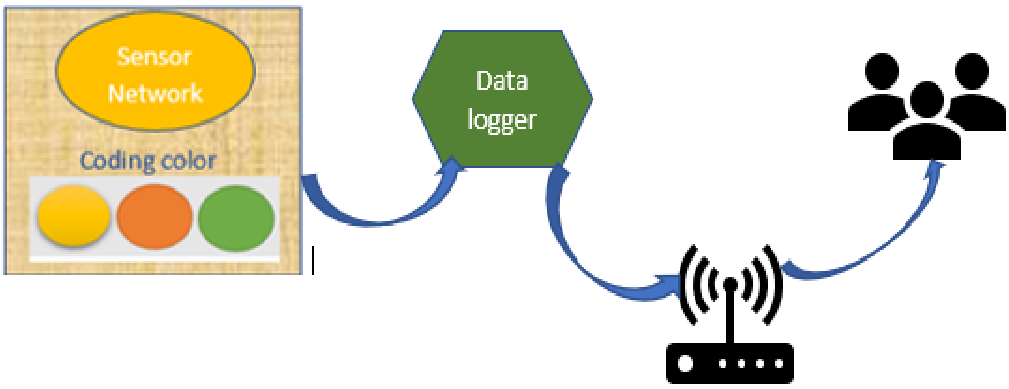

Figure 3.

B. Stormwater Management Material Used for Pole Installation

Activity	Supply List	Remark
Equipment/tools	water level sensors (HC-SRO4) Arduino MEGA 2560 Rev3 or SunFounder Mega 2560 R3 Temperature sensor (DS18B20 Arduino 125 degrees centigrade) Humidity sensor (DHT22) Containers to hold the sensors tipping bucket rain gauge safety color coding light will be coded as yellow (warning), coral color (flooded road), and green (clear).	
Hardware/software	Computer with Software Data logger (Adafruit Data Logging Shield) Antenna cable – 2.4 GHz, 6dBi, IPEX 170 mm long Cellular antenna Internet wifi Bread board Jumper wire (11.8in) 10mm LED's Solar panel 12 V batteries SD Card	software for reading the transmitted sensors data
Materials	Long Metal pole mast Rebar (metal) screws wires Gloves Padlock, hasps with screws. 5 by 18 inches metal sheet Ruler Water (one bucket) Hammer Drill kit Small bag of cement and sand	Screws for solar panel installation Some of these materials maybe available in the laboratory.
Record/Documentation	Camera Paper pen	Optional

Table 3.

VI. Stormwater management for Water Level Sensor with Hardware/Software Design

The HC-SRO4 is an ultrasonic water level sensor is low cost and easy to set up with measurable ranging distance of 2-400cm (0.2-4.0m). The HC-SR04 module is composed of ultrasonic transmitter, a receiver, and control circuits. it provides non-contact measurement with 3mm precision. It has four pins which are: Trigger, power (VCC), receiver is echo, and ground pin (GND). Its characteristics includes 5V DC operating voltage, 15° measuring angle, and 15mA operating current.

Also, the prototype operation of the ultrasonic sensor, humidity, and temperature sensor devices will generate data that will be interfaced with the microcontroller (Cypress/Arduino Uno ATmega328 microcontroller) that is connected to IoT Wi-Fi module coordinate of the node for real time data collection at the stream. The data can be sampled at an interval of less than 2s and it will be solar powered with a micro-SD card as backup storage. Other proposed water level sensors are MB7066, which is also ultrasonic but with longer distance range of about 20cm -1064cm. it will be connected to cellular communication module, solar power with rechargeable battery (12V 80 Ah), and 32-bit microcontroller for analysis. The surface flooding data obtained from this study will be used for flood risk assessment and planning.

A. **Architecture network 2**

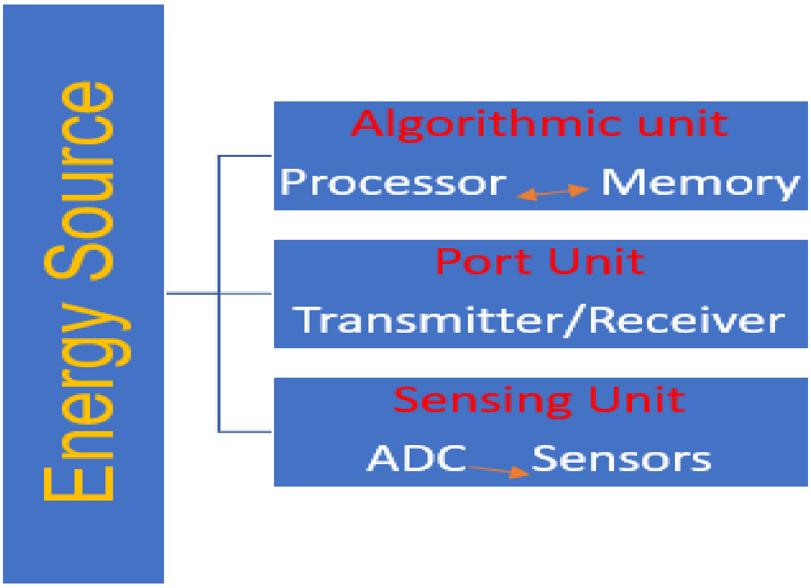

Figure 4.

Flooding is a global issue that affects mankind generally; therefore, this paper did an in-depth review of different studies conducted in various parts of the world. It details an overview of strategies that best suits stormwater management locally and worldwide[32]. Flooding has caused many human problems, especially for those residing in densely populated urban areas [3], but technological advances have evolved to solve many daily human problems. Natural events such as floods posed imminent dangers to lives, especially in the absence of an early warning to people in diverse environmental facets. [23] give an integrated optimization rule-based model to mitigate flooding impact on waterways. A flash flood early warning system study in the northeastern part (Hoang Su Phi) of Vietnam; used hydrology and geomorphological approach with a warning map to show the hazard level of precipitation for one to six days [15]. Most inexpensive technological designs are above water [29]to prevent environmental conditions and corrosions.

B. **Architecture network design 3**

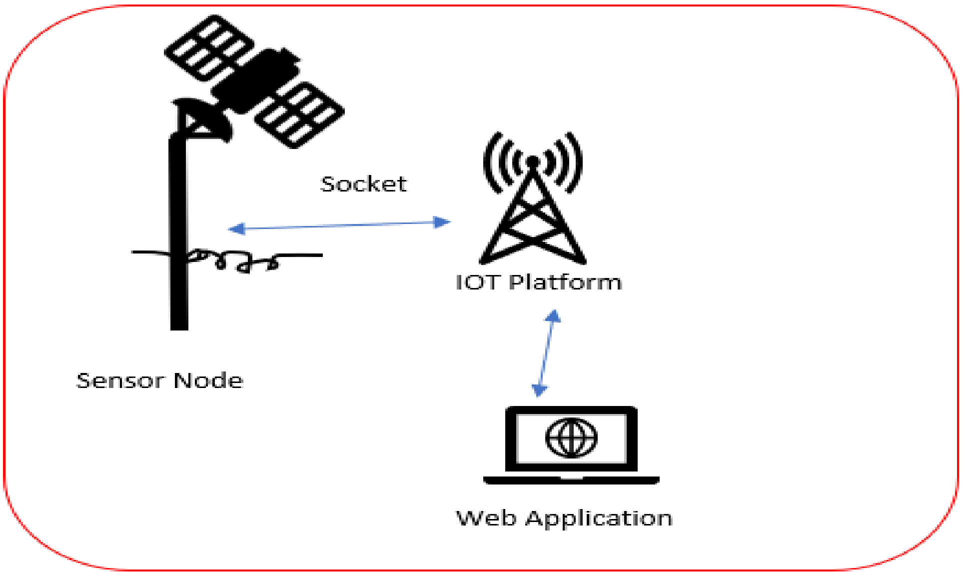

Figure 5.

[16]. studied urban flood motes sensors system interfaced with network video record for in-situ water logging monitoring images during flooding. The water level sensors were arranged to receive water level information, and the network cameras were received video information. The signals received from the water level sensors and network cameras are transmitted to the data processing module that runs through a computer server, providing information to end-users [16].

Furthermore, the result of the study by Lockridge 2016 showed that functional testing done at the Dauphin Island Sea Lab found that the temperature measurement was 0.154oC with a highly correlated regression temperature device value r2 = 0.99 which proved that the devices functional testing evaluation was adequate [11].

C. SISWM^2 network mesh

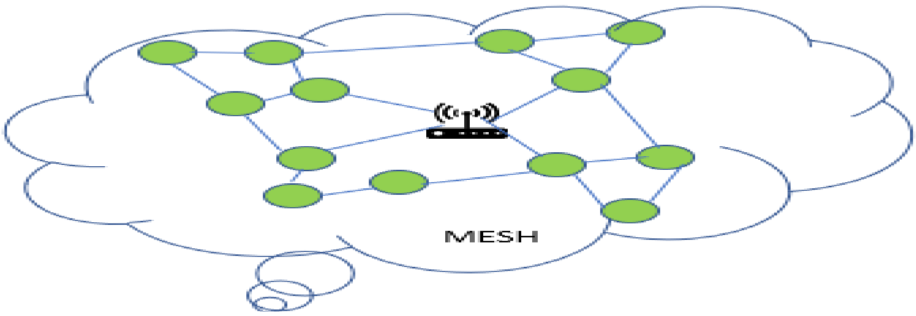

Figure 6.

Moreno et al. developed a RiverCore IoT equipment at Colima Mexico hydrological area that describes a static module and mobile drifter node system with a web-based data acquisition platform interfaced with IoT and 3G cellular networks. The fixed module design utilizes the Message Queuing Telemetry Transport (MQTT), an open machine-to-machine low power network connectivity. The MQTT, along with encryption and security systems, sends ongoing information bundles from fixed hubs to a server that stores information in a dataset. The fixed RiverCore module senses various variables/factors in a river/stream, for example, water height, width, and flow speed, by utilizing an ultrasonic distance sensor. A RiverCore fixed hub comprises five unique gadgets: a regulated power supply, a solar charge controller and a 12 V 80 Ah battery, a 32-bit microcontroller unit, and a 3G cellular modem electronic board. The mobile drifter node interfaced with a micro-SD to retrieve measured data and a GPS module that gets information on time, location, and speed variables. The device has a magnetic switch that activates it to log data at one-second stretches for twenty-four hours. It moves through the waterway bed, and the data obtained is stored on the microSD card for analysis [13].

Another study by [19]. at the Katulampa Dam, Bogor, provide the results of research work in which they developed two devices for early detection system of flood disasters. The result showed that the ultrasonic sensors were adequate with 97% accuracy in detecting moving water levels that function in a range of 14-250 cm with the fastest message delivery test time of 8.20 and the longest time of 33.3 seconds [19].

Vitry et al. researchers conducted a study utilizing an adaptable qualitative flood monitoring approach with deep convolutional neural network machine learning models for water image segmentation to extract flood level fluctuations. The process was to predict floodwater trends through surveillance images and static observer flooding index technology to remotely sense water level fluctuations [14].

[27] did a case study utilizing conceptual models involving river flood analysis in Flanders, Belgium. The researchers used a predictive model controller to anticipate rainfall and flow conditions with a prediction error method that decreased uncertainties. The predictive model controllers MPC result merits include its geographical changing prediction coordination. Their research brings about a projected damage cost decrease from a flood occasion with a lessened outcome of 58% flood hazard in regional areas [27].

Also, to get accurate water level data, Ley et al. suggested using a median absolute estimator to detect outliers. Also**,** [4] research created an algorithm for eliminating outliers from water data/information obtained from sensors by Z-score modification. Sensors estimated anomaly mainly occurs when sensors wave reflection occurs before arriving at the stream's outer surface [10][4].

Also, a waterproof device is essential to protect sensors from harsh environmental conditions. Shi et al. did a laboratory water column test on six units of water depth sensors to determine the sensor's performance for eight weeks. The sensor data was measured at six-minute intervals and deployed in the field for about one year. The study found that the first sensor didn't function appropriately because of water entry into the device. The other waterproof sensors were not damaged [22]. IoT portrays an advanced character for information trade and communication for objects and involves the dynamic connection of hardware and software to the global internet infrastructure organization [6]. [2] provided an insight into data aggregation algorithms for prolonging wireless sensor networks lifetime when gathering sensory, audio, or imagery data that may require compression. Accumulation of information is a strategy to enhance energy use, decreasing data overlap and redundancy [2]. Kim et al. discuss Real-time flood prediction through hydraulic and probabilistic models to estimate runoff patterns in urban areas. Lizhen examined hourly water prediction through an artificial neural network (ANN) to predict floods.

Sung et al. 2017 discuss the use of hourly rainfall and water level series from six gauging stations from the Han River creek in South Korea to predict flood water levels. The researchers formed ANN models for water level gauges with data correlation statistical analysis. The floodwater level rises at the river because of the backwater effect and tidal conditions. The outcome demonstrated the consideration of numerous water level data that gave accurate water level gauges with prominent precision [24].

Sunkpho and Ootamakorn established a wireless flood monitoring network in southern Thailand (Nakhon Si Thammarat) to detect information for early notification and alleviation of floods in the region. It has three sections: sensors, data transmission and processor, and database server. The STARFLOW ultrasonic sensors were deployed underwater, which estimates velocity and water level with a range of 0 to 5 meters. The precipitation sensors, a tipping bucket rain gauge, estimates precipitation. The data from the sensors was sent to the GPRS Data Unit for information handling and transmission to the control center while the database server processes and displays information for users [25].

The timing of flood prediction is crucial to flooding forecast [7]; an experimental case study in Turkey that utilized tree-based model predictive control showed the state of flood risk assessment. The study found that higher releases during six-hour and 12hour short forecast horizons are detrimental in the downstream reservoir. An 18h or more forecast horizon produces optimal downstream-timeline flood control [26].

VII. Conclusion

In conclusion, urban flooding occurs when stormwater exceeds the drainage capacity during storm occasions, mostly when the inlet drains are blocked with debris. Thus, there is an increasing need to create sensors network systems to alert people/residents of imminent dangers and potential flooding in a particular urban area. Expectedly, the incorporation of existing aging stormwater infrastructure (storm drainage system, bridges, waterways, roads) with sensors network will diminish traffic interruption, economic loss, and health issues.

Reference

[1]. Aladesote, O. J., & Hunter, J. (2019). Stormwater Management Utility Fees: A review. International Journal of Research Publication, 40(1). http://ijrp.org/paper detail/794

[2]. Abbasian Dehkordi, S., Farajzadeh, K., Rezazadeh, J., Farahbakhsh, R., Sandrasegaran, K., & Abbasian Dehkordi, M. (2019). A survey on data aggregation techniques in IoT sensor networks. *Wireless Networks*, *26*(2), 1243-1263. https://doi.org/10.1007/s11276-019-02142-z

[3]. Aladesote, O. J., & Hunter, J. (2020). Stormwater efficiency of Bioretention functions and reactor modelling systems. *International Journal of Advances in Scientific Research and Engineering*, *01*(11), 01-09. https://doi.org/10.31695/ijasre.2020.33921

[4]. Bae, I., & Ji, U. (2019). Outlier detection and smoothing process for water level data measured by ultrasonic sensor in stream flows. *Water*, *11*(5), 951. https://doi.org/10.3390/w11050951

[5]. Butler, D., Digman, C., Makropoulos, C., & Davies, J. W. (2018). *Urban drainage*. CRC Press.

[6]. Dachyar, M., Zagloel, T. Y., & Saragih, L. R. (2019). Knowledge growth and development: Internet of things (IoT) research, 2006–2018. *Heliyon*, *5*(8), e02264. https://doi.org/10.1016/j.heliyon.2019.e02264

[7]. Duncan, A., Chen, A. S., Keedwell, E., Djordjevic, S., & Savic, D. (2011). Urban flood prediction in real time from weather radar and rainfall data using artificial neural networks.

[8]. Ham, J. M. (2013, December). Using Arduinos and 3D-printers to build research-grade weather stations and environmental sensors. In *AGU Fall Meeting Abstracts* (Vol. 2013, pp. H43H-1573).

[9]. Kim, H., Keum, H., & Han, K. (2019). Real-time urban Inundation prediction combining hydraulic and probabilistic methods. *Water*, *11*(2), 293. https://doi.org/10.3390/w11020293

[10]. Leys, C., Ley, C., Klein, O., Bernard, P., & Licata, L. (2013). Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of Experimental Social Psychology*, *49*(4), 764-766. https://doi.org/10.1016/j.jesp.2013.03.013

[11]. Lockridge, G., Dzwonkowski, B., Nelson, R., & Powers, S. (2016). Development of a low-cost arduino-based sonde for coastal applications. *Sensors*, *16*(4), 528. https://doi.org/10.3390/s16040528

[12]. Marin-Perez, R., García-Pintado, J., & Gómez, A. S. (2012). A real-time measurement system for long-life flood monitoring and warning applications. *Sensors*, *12*(4), 4213-4236. https://doi.org/10.3390/s120404213

[13]. Moreno, C., Aquino, R., Ibarreche, J., Pérez, I., Castellanos, E., Álvarez, E., Rentería, R., Anguiano, L., Edwards, A., Lepper, P., Edwards, R. M., & Clark, B. (2019). RiverCore: IoT device for river water level monitoring over cellular communications. *Sensors*, *19*(1), 127. https://doi.org/10.3390/s19010127

[14]. Moy de Vitry, M., Kramer, S., Wegner, J. D., & Leitão, J. P. (2019). Scalable flood level trend monitoring with surveillance cameras using a deep convolutional neural network. *Hydrology and Earth System Sciences*, *23*(11), 4621-4634. https://doi.org/10.5194/hess-23-4621-2019

[15]. Nguyen, T. N., Pham, C. X., Nguyen, H. Q., & Dang, T. N. (2018). Establishing an early warning system for flash floods in Hoang Su PHI district, ha Giang province, Vietnam. *Singapore Journal of Tropical Geography*, *40*(2), 312-333. https://doi.org/10.1111/sjtg.12276

[16]. Ni-Bin Chang, & Da-Hai Guo. (n.d.). Urban flash flood monitoring, mapping and forecasting via a tailored sensor network system. *2006 IEEE International Conference on Networking, Sensing and Control*. https://doi.org/10.1109/icnsc.2006.1673241

[17]. O'Driscoll, M., Clinton, S., Jefferson, A., Manda, A., & McMillan, S. (2010). Urbanization effects on watershed hydrology and in-stream processes in the southern United States. *Water*, *2*(3), 605-648.

[18]. Olatunde J Aladesote, Marc J Louise Caballes, & Oludayo Alamu, "Risk Assessment for Stormwater Management and Green Infrastructure in an Urban Area," International Research Journal of Advanced Engineering and Science, Volume 7, Issue 2, pp. 1-7, 2022.

[19]. Indrasari, W., Iswanto, B. H., & Andayani, M. (2018). Early warning system of flood disaster based on ultrasonic sensors and wireless technology. *IOP Conference Series: Materials Science and Engineering*, *335*, 012005. https://doi.org/10.1088/1757-899x/335/1/012005

[20]. Saliba, S. M., Bowes, B. D., Adams, S., Beling, P. A., & Goodall, J. L. (2020). Deep reinforcement learning with uncertain data for real-time stormwater system control and flood mitigation. *Water*, *12*(11), 3222. https://doi.org/10.3390/w12113222

[21]. Sen, D. (2013). Real-time rainfall monitoring and flood Inundation forecasting for the city of Kolkata. *ISH Journal of Hydraulic Engineering*, *19*(2), 137-144. https://doi.org/10.1080/09715010.2013.787718

[22]. Shi, B., Catsamas, S., Kolotelo, P., Wang, M., Lintern, A., Jovanovic, D., Bach, P. M., Deletic, A., & McCarthy, D. T. (2021). A low-cost water depth and electrical conductivity sensor for detecting inputs into urban stormwater networks. *Sensors*, *21*(9), 3056. https://doi.org/10.3390/s21093056

[23]. Shishegar, S., Duchesne, S., & Pelletier, G. (2019). An integrated optimization and rule-based approach for predictive real time control of urban stormwater management systems. *Journal of Hydrology*, *577*, 124000. https://doi.org/10.1016/j.jhydrol.2019.124000

[24]. Sörensen, J., Persson, A., Sternudd, C., Aspegren, H., Nilsson, J., Nordström, J., ... & Mobini, S. (2016). Re-thinking urban flood management—Time for a regime shift. *Water*, *8*(8), 332.

[25]. Sung, J., Lee, J., Chung, I., & Heo, J. (2017). Hourly water level forecasting at tributary affected by main river condition. *Water*, *9*(9), 644. https://doi.org/10.3390/w9090644

[26]. Sunkpho, J., & Ootamakorn, C. (2011). Real-time flood monitoring and warning system. *Songklanakarin Journal of Science & Technology*, *33*(2).

[27]. Uysal, G., Alvarado-Montero, R., Schwanenberg, D., & Şensoy, A. (2018). Real-time flood control by tree-based model predictive control including forecast uncertainty: A case study reservoir in Turkey. *Water*, *10*(3), 340. https://doi.org/10.3390/w10030340

[28]. Vermuyten, E., Van Uytven, E., Meert, P., Wolfs, V., & Willems, P. (2020). Real-time river flood control under historical and future climatic conditions: Flanders case study. *Journal of Water Resources Planning and Management*, *146*(1), 05019022. https://doi.org/10.1061/(asce)wr.1943-5452.0001144

[29]. White, M. D., & Greer, K. A. (2006). The effects of watershed urbanization on the stream hydrology and riparian vegetation of los Peñasquitos Creek, California. *Landscape and Urban Planning*, *74*(2), 125-138. https://doi.org/10.1016/j.landurbplan.2004.11.015

[30]. Wickert, A. D. (2014). The ALog: Inexpensive, open-source, automated data collection in the Field. *Bulletin of the Ecological Society of America*, *95*(2), 166-176. https://doi.org/10.1890/0012-9623-95.2.68

[31]. Willuweit, L., & O'Sullivan, J. J. (2013). A decision support tool for sustainable planning of urban water systems: Presenting the dynamic urban water simulation model. *Water Research*, *47*(20), 7206-7220. https://doi.org/10.1016/j.watres.2013.09.060

[32]. Homepage | National Oceanic and Atmospheric Administration (noaa.gov)

[33]. Aladesote, O. J. (2022). Cost-benefit analysis of green infrastructure for sustainable stormwater management of the built environment. *International Journal of Research Publications*, *97*(1). https://doi.org/10.47119/ijrp100971320222992