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A Systematic Review and Meta-Analysis on Water Quality Monitoring System

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***Abstract*: The use of remote sensing has been used and even applied in different technologies. This paper discusses the possible application of remote sensing in monitoring water quality in the Philippines. Usually, water samples are collected and analyzed in the laboratory for information on water quality parameters. This tedious process may improve through assessing the water quality parameters directly from satellite imagery. Thus, the paper provides an overview of remote sensing. A total of 15 papers were reviewed about water quality monitoring and remote sensing technology and the challenges and opportunities for the Philippines in adopting this technology. The result is beneficial for the plan in developing a water quality monitoring program in the country.**

***Keywords*: Philippine lakes, geographic information system, water quality monitoring system, water quality, remote sensing.**

1. Introduction

If water quality is poor, it affects not only aquatic life but the surrounding ecosystem as well. And quality testing is an essential part of environmental monitoring. Water quality study determines the chemical, physical and biological characteristics of water bodies and identifies the possible contamination sources that degrade water quality. The Philippines is surrounded by water. There are 72 numbers of lakes in the Philippines (WEPA, 2018). The lakes are either tectonic, kettle, or maare in type. These bodies of water are essential for fisheries because of their domestic, agricultural, industrial, and recreational uses (Guerero III, 1999). Brillo (2015) described Lakes as essential to the preservation of the ecosystem. The water resources serve as habitats for various flora and fauna and play a critical role in natural processes, such as climate mediation and nutrient cycling.

Caraig (2018) mentioned that the Philippines is facing huge challenges in natural resources and pollution. Many parts of the water are polluted; this is a common problem and scenario in the Philippines. Pasig River is an important river in the Metro Manila, Philippines, since it provides food, livelihood, and transport to its residents and connects two major water bodies; Laguna de Bay and Manila Bay. Gawande (2016) reiterated that it is now considered the toilet bowl of Metro Manila due to the large volume of wastes dumped into the river.

Diseases related to poor water and sanitation conditions have over 200 million cases reported annually, causing 5–10 million deaths worldwide. Water quality monitoring has thus become essential to the supply of clean and safe water. Conventional monitoring processes involve the manual collection of samples from various points in the distribution network, followed by laboratory testing and analysis. This process has proved ineffective since it is laborious, time-consuming, and lacks real-time results to promote proactive response to water contamination (Pule et al., 2017). Additionally, marine resources in the Philippines face increasing pressure from overfishing, destructive fishing practices, habitat destruction, declining water quality, and limited management capacity (Tupper et al., 2015).

Meanwhile, the degradation of water quality is due to the disposal of a large quantity of wastewater, including sewage. Almost if not all the tropical Lakes in the world face similar situations due to pollution caused by anthropogenic activities. In water bodies, biochemical oxygen demand or known as BOD is an indicator of organic matter; fecal coliform is an indicator of sewage pollution; pH represents the ionic composition of water, and dissolved oxygen means the health of the water. These significant water quality parameters are usually prescribed (Sheela et al., 2013). Moreover, water hardness varies depending on the source, treatment procedures, and pipeline conditions, among others, though not of immediate concern in water quality control but may have significant health, infrastructural, or industrial effects (Sumalapao et al., 2017).

One way to investigate the influence of a water-quality trend is to assess the statistical significance of the direction. While trend analysis can assign this statistical significance, considering how a trend might be environmentally significant is not typically addressed (Ryberg et al., 2014). Effective management and protection of water resources rely upon understanding how water-quality conditions change over time (Shoda et al., 2019).

Nowadays, urban development is envisioned to integrate multiple information and communication technology (ICT), “Big Data,” and Internet of Things (IoT) solutions in a secure

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fashion to manage a city's assets for sustainability, resilience, and livability. Meanwhile, water quality monitoring has evolved to the latest wireless sensor network (WSN) based solutions in recent decades (Chen and Han, 2018). The use of remote sensing and GIS in water monitoring and management has been long recognized. This covers different parameters such as monitoring the temperature, pH, dissolved oxygen, BODs, electrical conductivity, nitrate, phosphate, and chlorophyll-a (Al-Fahdawi, 2015).

Assessing waters and watersheds accurately, effectively, and efficiently requires working collaboratively and striving for methods and data comparability. Factors that can impede collaboration and comparability include critical differences in monitoring design, sampling protocols and analytical techniques, data management, and data accessibility (NWQMC, 2004). In response to the growing problem in water quality, the government enacted the Philippine Clean Water Act in 2004 and its Implementing Rules and Regulations the year after. The Act and its IRR require an integrated approach, more vital collaboration among stakeholders, and promotion of co-ownership of the water bodies (DENR, 2013).

The objective of the study was to assess the status of water quality monitoring in the Philippines, to evaluate the contributions and approaches addressed in the planning of water quality monitoring systems, and to determine the opportunities and challenges can be brought out to address the needs in the country's water quality monitoring.

2. Methodology

The researchers used different research databases to gather the most comprehensive and frequently used data sources for reviewing quality publications and assessing their contributions to this study. The publications included journal papers and research articles.

Researchers manage all papers on water quality monitoring and remote sensing device being used in other countries. Likewise, researchers also assess the different contributions and accomplishments; the data will be the basis of the researchers the applicability and potential of the system for the Philippine setting. After evaluating the papers, researchers will cite some challenges that are being mentioned in the previous studies.

3. Discussion

In the study of Dimzon et al., (2018), three of the seven lakes of San Pablo City collected lake water samples. These are Palakpakin (PAL), Sampaloc (SAM), and Pandin (PAN), and they are considered volcanic crater lakes, which are located within a catchment area of 27.5km^2. The lakes are within the watershed of Laguna de Bay. The lakes are also found in San Pablo City, which has a population of about 250,000 according to the Philippine Statistics Authority year 2010. As part of the initial characterization of the lake, the results in the study showed that some conventional parameters were measured. The parameters included surface temperature, pH, and dissolved oxygen. The results of these measurements were compared to the limits set by the Philippines' Department of Environment and Natural Resources (DENR) for each freshwater type in its Administrative Order No. 2016–08 released in May 2016. PAL and SAM can be classified as Type C freshwater. This means that the water in these lakes can be used in fishery, agriculture, and non-contact recreational activities like boating. On the other hand, PAN is considered as a Type B fresh water for bathing and swimming.

Meanwhile, in the study of Roa et al. (2017), monitoring water quality is one of the crucial considerations for mariculture activity. Water quality determines the conditions in which living matter can exist. The quality of the water varies from place to place, with the seasons and climate. Thus, seasonal water quality monitoring of the three mariculture parks in Northern Mindanao, located in Balingasag, Misamis Oriental, Surigao del Norte, and Lopez Jaena, Misamis Occidental, was carried out from April 2013 to May 2014. The temperature, dissolved oxygen, salinity, pH, total suspended solids, depth, water transparency, and water nutrients significantly varied between seasons. Low water temperature and high DO levels were observed during the northeast monsoon. The year-round nutrient concentrations in the Parks were observed at evident levels. Some areas surpassed the standard concentrations for marine fish culture, signifying possible pollution in the water. Generally, however, these Physico-chemical parameters in the three mariculture parks are still within the allowable limit for marine fish production.

Assessing waters and watersheds accurately, effectively, and efficiently requires working collaboratively and striving for methods and data comparability. Factors that can impede collaboration and comparability include critical differences in monitoring design, sampling protocols and analytical techniques, data management, and data accessibility (Scott & Frost, 2017).

The quality of water in various water bodies is rarely constant in time. While there may be some relationship between the rates of change of different variables, others alter independently. The larger the number of samples from which the mean is derived, the narrower will be the limits of the potential difference between the observed and accurate means. Variations in WQ are caused by changes (increase or decrease) in the concentration of any of the inputs to a water-body system (Magtibay et al, 2015).

A. Meta-analysis

Table 1 summarizes contributions and approaches addressing water quality monitoring system/plan and remote sensing planning. Several studies were mentioned, including their significant contributions related to water quality and remote sensing.

The review investigated water quality and public health risks associated with its consumption. Explaining land-use practices, weather patterns, and their interactions influence water quality. Contrary to the notion that roof water is safe, data point to Physico-chemical and microbial contamination via atmospheric deposition, leaching and storage/conveyance utilities, and fecal contamination. However, epidemiological studies linking water consumption to public health risks are scarce, especially in developing countries like the Philippines. This research study reflects the lack of epidemiological research and confounding factors such as high disease burden. Also, it pointed out the inefficiencies of the current practice of discharging untreated sewage into the surface water and causing mainly in the river water and unsuitability of river water of water from the different city rivers and lakes.

To minimize the public health risks, the researchers recommend first the implementation of a risk assessment framework integrating laboratory analytical results and sanitary inspection risk analysis. Such a framework will enable proper prioritization and targeting of engineering/technological

Table 1
Summary of contributions and approaches addressing planning of Water Quality Monitoring System/Plan

Author/year	**Main contributions**
(Al-Fahdawi et al. 2015)	The remote sensing and GIS techniques are the most effective, cheaper, and valuable tools in monitoring water quality parameters in freshwater bodies (lakes, rivers, and reservoirs) compared to in situ. In contrast, the measurement is restricted to selected sampling points. In the future, the solution to water quality issues can be solved rapidly using remote sensing and GIS technologies coupled with computer modeling.
(Sheela et a., 2013)	Satellite and aircraft remote sensing systems were used in the assessment of water quality parameters, such as temperature, chlorophyll-a, turbidity, total suspended solids, and Secchi disk depth for Lakes and reservoirs
(NWQMC, 2004)	The monitoring design must be developed to meet the monitoring objectives. Factors that must be considered at this stage of the process include the environmental setting, location of sampling sites, frequency of sample collection, the constituents to be measured, and the methods used in the field and the laboratory.
(Gholizadeh, 2016)	The use of remote sensing in water quality assessment can be a helpful tool. Remote sensing has illustrated strong capabilities to monitor and evaluate the quality of inland waters. Remote sensing techniques have been widely used to measure the qualitative parameters of water bodies (i.e., suspended sediments, colored dissolved organic matter (CDOM), chlorophyll-*a*, and pollutants). A large number of different sensors onboard various satellites and other platforms, such as airplanes, are currently used to measure the amount of radiation at different wavelengths reflected from the water's surface.
(Chang, et al., 2015)	Remote sensing technologies involve using a wealth of multidisciplinary approaches to solve highly interdisciplinary problems and provide vital monitoring capacity for terrestrial, atmospheric, and aquatic environments. As each disciplinary area evolves, the follow-up utilization must be holistically modified by various mission-oriented programs.
(Qin, et al., 2017)	Practical application of the integrated sensing system as a simplification of the conventional laboratory-based analytical methods for on-site water quality monitoring. The system can be exploited for monitoring other water quality parameters such as conductivity, heavy metals ions, dissolved oxygen, and bacteria.
(Chung & Yoo, 2015)	A wireless sensor network (WSN) with deployed field servers, which collect information on the water quality from a wide target area, is designed to detect water pollution in streams, rivers, and coastal regions. The water pollution data, such as dissolved oxygen (DO), hydrogen ion exponent (pH), conductivity, turbidity, depth of water, and temperature, are transmitted between the field servers, and finally, to the base station (BS) in a self-organizing wireless sensor network using water quality sensor modules.
(Guo, et al., 2017)	Aerial photographs were the earliest used remote sensing data in wetland studies. In recent years, aerial photography has been used as a type of high spatial resolution imagery to classify wetlands, identify wetland species, and test the accuracy of other classifications or maps.
(Xiaomin, et al., 2016)	The comprehensive water assessment method could achieve the analysis and assessment of the monitored water quality data. Then, the suggested advice for decision support which users could easily understand will be provided according to the achieved assessing result through the combination of the ontology reasoner and inference rules. The validation with five sets of water samples has proved the accuracy and reliability of the system.
(Novero et al., 2018)	The use of digital maps requires some type of attribution to be attached to the map units. This includes semi-automated map preparation using GIS software to prepare map themes, which can be updated dynamically for land use plans. The quality of GIS maps, however, is dependent on the resolution and accuracy of input data. The input data should have significantly high spatial resolution and accuracy to have a better and more accurate GIS map.
(Tomic, et al., 2015)	Remote sensing methods offer the possibility of creating a system for monitoring changes in the coal basin, including water quality monitoring, to define the emission of pollutants in water, the concentration of contaminants in the water, and the spatial distribution and potential environmental pollution. The importance of the application of remote sensing and GIS refers to the need to develop new technologies for monitoring emissions to water in the geographic space, as well as the opportunity to discover their potential impact on the natural and human environment, and the ability to obtain quick and reliable information will be used to develop measures for the preservation and improvement of environmental quality in large mining basins.
(Zhuo and Zhao, 2011)	The water quality monitoring subsystem provides the features and trend products of various water quality indicator parameters through the retrieval and time series analysis models based on remote sensing data. Using these parameters monitoring developments, the subsystem can further output a series of advanced data products such as water quality division and classification, lake eutrophication assessment, water pollution assessment. In addition, the subsystem also includes an application model management module to support modification, update, and customization of models.
(Pule et al., 2017)	Wireless sensor networks offer a good infrastructure for municipal water quality monitoring and surveillance. Their most significant benefit comes from affordability and the ability to conduct measurements remotely and in real-time. However, these networks have resource limitations in processing power, memory, communication bandwidth, and energy/power.
(Bokingkito and Llantos, 2017)	The design and development suggest that with the proper selection of the appropriate instruments for the water temperature sensors, the water monitoring system can efficiently assess the fisher folks in real-time water temperature monitoring at a low cost. The water analysis could also aid in preventing inevitable water environment occurrences, decision-making, proper planning, and management of the aquaculture industry. Aside from the water temperature, other parameters for the water quality such as dissolved oxygen, pH, ammonia, nitrates, salinity, and alkalinity could also help the fisher folks monitor and analyze the quality of the water.
(Pasternak et al., 2017)	They developed a self-powered biosensor for online water monitoring. Urine, a mixture of organic and inorganic compounds, was used to demonstrate its COD/BOD biosensing capabilities. The sensor was constructed from microbial fuel cells and an energy management system. In the presence of urine, the sensor was able to switch ON the sound and light cues, which lasted for at least two days, and in the long run, the sensor was successfully operated for 150 days. The interpretation of the signal is intuitive, either based on its frequency or simply its presence. Thus, a fully automated biosensor is envisaged in off-grid areas, such as lakes or water sources, where it can be a part of an early warning system.

interventions, public education, and housekeeping programs. Support and participate in any advanced wastewater treatment programs and activities set by both national and local government and private and non-private institutions that remove unwanted nutrients and harmful bacteria, using “pump-out” stations for the vessel’s sanitation device, using as many “green” products as possible at home, and reducing or eliminating the use of fertilizers, herbicides, and pesticides. Lastly, to integrate river water pollution management and maintain ecologically to achieve healthy urban development.

Presently, the thought thinks of various sorts of systems, sensors, information, data, and devices. In water quality checking framework incorporates remote detecting, Geographic Information System (GIS) is best and less expensive. These systems are utilized as instruments in checking the water quality. Satellite and flying machine remote detecting framework can be either passive or dynamic; latent sensor reacts to exterior upgrades. It records common vitality that is reflected or produced from the Earth's surface.

Conversely, dynamic sensors utilize inward boosts to gather information about the earth—underdeveloped nations utilize remote detecting to check water quality. Remote detecting outlined solid observing and assessing the nature of inland waters. Likewise, it is used to gauge the subjective parameters of water bodies. Utilizing programming devices like the Geographic Information System application delivers maps and different designs shown. It is intended to store, oversee, show, and dissect a wide range of geographic and spatial information. It also incorporates maps, layers, perception, geocoding, symbolism, database, stage, and preparing support. This will enhance essential leadership because of particular and point-by-point data around at least one area and simple record keeping.

B. Common Physicochemical Water Quality Parameters

pH is a measure of the degree of acidity or alkalinity of a solution. A pH of 7 is neutral, while below and above neutral is considered acidic and alkaline, respectively. For distribution systems, a pH between 6.0 and 9.0 is usually recommended (Pule, 2017). To improve conventional pH, many studies focused on developing microfabricated pH sensors with smaller dimensions, higher stability, more straightforward operation, and lower cost (Bana et al., 2014).

Turbidity indicates the concentration of suspended and colloidal material in water, and it is measured in nephelometric turbidity units (NTU). Drinking water should have turbidity that is less than 1 NTU (Pule, 2017).

One of the most commonly used temperature sensors is a thermistor made from metals. However, the technologies to fabricate low-cost, integrated pH and temperature sensors compatible with other water quality sensors are still being explored (Qin et al., 2018). Water temperature is considered another important parameter of water quality status and ecosystem state because it impacts physical, chemical, and biological reactions in water; affects aquatic plants; and controls dissolved oxygen levels in water (Chang et al., 2014).

C. Mapping Remote Sensing and GIS

Mapping serves as a product's output progress. With caption, legend, and other annotations, it gives users who are unconscious with remote sensing products more detailed information about monitoring results. The mapping module applies annotations editing and maps output function for producers. To meet the needs of water quality monitoring and management, remote sensing products and ground-based observation data must be visualized. In the traditional system, the visualization of water quality information is single, which mainly statically displays the water environmental data, including document, form, chart, etc. In addition to these common ways of visualization, the visualization subsystem displays the dynamic changes of water environmental data by animation, which can cause the effect of gradient according to visual continuity (Zhou and Zhao, 2011).

GIS information (e.g., aerial photographs, land-use maps, road maps) can be used to evaluate potential locations, followed by a field visit to confirm the location (Borden and Roy, 2015). Many environmental engineering technologies for nutrient removal have been developed to secure tap water sources and improve the drinking water quality; various watershed management strategies for eutrophication control are moving to highlight the acute need for monitoring the dynamics and complexities that arise from nutrient impacts on water quality status and ecosystem state, both spatially and temporally. These monitoring methods and data are associated with local point measurements, airborne remote sensing, and space-borne satellite images of spatiotemporal nutrient distributions, leading to accurate environmental patterns (Chung & Yoo, 2015).

D. Challenges

One of the most significant difficulties in checking water quality is gathering a vast number of tests with the end goal to guarantee precise and solid investigation. In such a manner, manual techniques present extensive unpredictability and are viewed as ineffectual. Ongoing observing empowers early cautioning ability to ensure the auspicious reaction to water pollution (Pule, 2017).

The more significant part of the investigations has concentrated on optically dynamic factors, for example, chl-a, CDOM, TSS, and turbidity. Be that as it may, various imperative water quality factors, for example, PH, add up to nitrogen (TN), smelling salts nitrogen (NH3-N), nitrate-nitrogen (NO3-N), and broke down phosphorus (DP), and so on are not all around researched because of their frail optical attributes and low flag clamor proportion. Regardless of the made reference to constraints, remote detecting is a valuable instrument for water quality checking (Gholizadeh, 2016).

The remote detecting estimation of water quality experiences relatively low spatial goals, making it hard to screen water quality for freshwaters, such as waterways, channels, and lakes in the urban zone. Attributable to the development in smart cities and the Internet of Things, the system found in the urban area, both wired and remote, is proliferating, and new system conventions have been created (Chen and Han, 2018).

E. Opportunities

The Philippines now has active satellites in space that can be used in water quality monitoring.

The country launched its first two microsatellites, Diwata-1 in 2016 and Diwata-2 in 2018. Diwata-1 was decommissioned in March 2020, while Diwata-2 remains in space. Maya-1, the predecessor of the three cube satellites, was launched into space in June 2018 and was deployed into orbit two months after. It returned to earth in December 2020. Maya-2 is currently in space after being launched into the ISS in February and deployed into orbit in March. Maya-3 and Maya-4 were designed and developed by scholars of the Department of Science and Technology's (DOST) Space Technology and Applications Mastery, Innovation, and Advancement (STAMINA4Space) Program. Philippine Space Agency director-general Joel Marciano, Jr. said the two cube satellites would help improve the data gathering of Filipino experts in agriculture, weather monitoring, and disaster management, particularly in getting information from rural areas (CNN Philippines, 2021).

Satellites are essential in providing the information government agencies receive during times of natural disasters. Satellite images would also be helpful for students and professionals researching in their respective fields.

4. Conclusion and Recommendation

One of the qualities of the observing arrangement is the accentuation of criticism at each progression. The fruitful use of the observing structure will guarantee that the aftereffects of water quality checking can be utilized to comprehend, ensure, and reestablish our waters.

Contaminants, for example, substances, supplements, and overwhelming metals, are conveyed from homesteads, industrial facilities and urban areas by stream and waterways into our sounds and rivers; from that point, they make a trip out to inlet. In the interim, marine debris and jetsam, mainly plastic, is blown in the breeze or washed in using tempest channels and sewers. Others are originated from creatures, plants, microscopic organisms, and parasites that interface straightforwardly with one another. Contaminations and contaminants can harm or damage these life forms that can make a chain impact, jeopardizing the whole sea-going situation.

Satellites are essential in providing the information that government agencies receive during times of natural disasters. Application of Geographic Information System and sensors must be considered in water quality checking in the country considering that there are satellites that may use on this.

Correspondence, coordination, and joint effort among various associations locally or globally are needed to think of Water Quality Monitoring Program in the Philippines.

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