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Integrated Technologies for Low Cost Environmental Monitoring in the Water Bodies of the Philippines: A Review

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ABSTRACT

Water is an important commodity that is becoming scarce due to man-made and natural destruction. The Philippines has abundant water resources but the rapid development, anthropogenic activities, and poor policy implementation in the country leads to the deterioration of water quality in its water bodies. Water quality monitoring (WQM) is a tedious and costly process that can impinge countries with limited resources. On the other hand, emerging technologies on wireless sensor network, energy harvesting, remote sensing, and geographic information system (GIS) have been the focus of various researches in order to achieve a precise, periodic, real-time, and low-cost water quality monitoring. In this work, these enabling technologies are reviewed to evaluate their applicability in the assessment, management, and rehabilitation of contaminated water bodies in the Philippine context. To carry out this study, the water quality monitoring program, existing technologies being employed, and the challenges in implementing a nationwide and comprehensive WQM processes were identified. Then, an overview of the qualitative state of the water resources in the country is sought in order to accentuate the need for more suitable alternative techniques.

INTRODUCTION

One of the world's environmental problems facing nowadays is water contamination, which relates to the alteration of surface waters, underground waters or the marine environment with a thermal or material pollution, exceeding levels of heavy metals and poisonous chemicals. Monitoring and assessing the quality of surface waters are critical for managing and improving its current condition (Ritchie et al. 2003). Moreover, there are five to ten million deaths worldwide annually due to water-related diseases. Also, the rapid increase of environmental pollution makes an urgent need for research and policy making for the conservation of the environment (Chung & Yoo 2015).

In situ measurements and collection of water samples for subsequent laboratory analyses are currently used to evaluate water quality (Ritchie et al. 2003) which are usually employed with the tedious (Capella et al. 2010), costly and time-consuming (Slonecker et al. 2010) traditional detection methods. While, such measurements are accurate for a point in time and space, they do not give either the spatial or temporal view of water quality needed for accurate assessment or management of water bodies (Ritchie et al. 2003). Also, the detection devices and methods existing in the market for heavy metals monitoring are usually expensive (Lin & Huang 2014) and employ off-line measurements. This is one of the reasons why monitoring levels of heavy metals are occasionally conducted. Fortunately, technology breakthroughs in remote sensing (RS), geographic information system (GIS), renewable energy (RE), and wireless sensor networks (WSN) have already opened up various research opportunities in water quality monitoring in aquatic areas, that promise more convenient and cost-effective alternative methods.

There have been various attempts to integrate different systems and technologies to field measurements and environmental monitoring campaigns. Most of which employ RS and GIS techniques for land use mapping, water quality modelling, and hydrographic modelling to achieve a predictive model that will best describe the existing environmental state of an area. By employing RS-GIS techniques, a permanent geographically located image database as a baseline for future comparison is also provided (Ritchie et al. 2003). One example of employing a highly integrated measurement is the works of Hartnett & Nash (2015), which presented a novel approach by integrating numerical modelling with field measurements and remote sensing and employed GIS to analyse their datasets. Environmental monitoring studies effectively employed remote sensing technologies, either as input data or as an analytical tool (Dåbakk et al. 2000, Dlamini et al. 2016, Wu et al. 2014). Many studies include the use of aerial photography, multispectral and hyperspectral image processing and interpretation, and spectroscopy.

This review describes first the status of the water quality monitoring program, the existing technologies employed, and the challenges in implementing monitoring protocols in the Philippines. Then, the current quality of water resources as reported by the mandated monitoring agency in the country, particularly on the physico-chemical and levels of heavy metals in the major water bodies, is presented in the paper. Lastly, this study evaluated existing approaches and tools that can be practically implemented in the Philippine context. Hence, the selection of scientific papers is mostly low-cost, open-source and freely available with recognized applications in the field of environmental monitoring that can be scaled up in a comprehensive but cost-effective water quality monitoring system. The objective of this review article, therefore, is to evaluate the possible applications and identify enabling technologies for water quality monitoring in three stages: contaminant detection, contaminant distribution mapping and modelling, and water quality data management and dissemination. This review further aims to assess the advantages of using these technologies and how they can be implemented in an integrated approach for water quality monitoring in a developing country such as the Philippines.

MATERIALS AND METHODS

In this review, we first searched official guidelines and circulars, reports, web materials, and scientific papers in order to describe the method, the status, and the underlying challenges of the water quality monitoring program in the Philippines. Then, peer-reviewed journal papers, case studies, and conference papers published from 2003 to 2017 were searched to identify and summarize techniques and methods on contaminant detection, contaminant distribution mapping and modelling, and water quality data management and dissemination. Note however, that this review is not comprehensive to cover all articles on the said topics, the literature search was rather limited to available full-text articles in ScienceDirect, Google Scholar and IEEE. Further, the result of the analysis of the articles reviewed is presented as the authors' perspective on the integration of the potential technologies to augment the conventional water quality monitoring through a simple framework (Fig. 1).

STATUS OF THE WATER QUALITY MONITORING PROGRAM IN THE PHILIPPINES

Water Quality Monitoring Program and Techniques

Water quality programs of the Philippines: Being an archipelago, the Philippines has 18 major river basins covering an approximate area of 1,08678 square kilometres, 421 major rivers with a total length of 3,172 kilometres and a long coastline reach of 36,289 kilometres (Environmental Management Bureau 2014). The country also has 79 lakes that are mostly used for fish production. A total of 688 water bodies have already been classified according to their intended beneficial use as of the year 2013 by the Environmental Management Bureau (EMB) of the Department of Environment and Natural Resources (DENR). And, 167 of these classified water bodies have multiple classifications thus leading to a total of 874 classifications. Out of 874 classified water bodies, 239 or about 27% are classified as Class AA and Class A, which are both intended for public water supply. While the majority of the Philippines' water bodies are classified as either for fishery, recreation, and supply for manufacturing processes after treatment or for recreational activities involving primary contact such as bathing, swimming, and skin diving. For coastal and marine water classification, a total of 58 water bodies were classified. Of the 58 water bodies, only five are designated as protected marine habitat while majority are intended for contact recreation and aquaculture production (Environmental Management Bureau 2014).

Since year 2006, various efforts in reinforcing the implementation of the Clean Water Act (CWA) of 2004 were observed in the country. Most of which are significant outputs from a technical cooperation project between Philippines and Japan. The Philippines' endeavours on water quality management were evident in the recent issuance of the DENR's Administrative Orders (DAO) and the increase of approved water quality management areas (WQMAs) to be placed under close monitoring. The DAO 2016-08 provides a new and more stringent water quality guidelines and general effluent standards while the DAO 2013-08 is the adoption of the integrated water quality management framework for the Philippines. There was also a remarkable increase of WQMAs in the country from only 5 in year 2010 to 31 as of June 2016 (Japitana et al. 2016). As provided in the CWA and DENR guidelines, areas identified as WQMA shall be closely monitored to address the water quality problems, sources of pollution, and beneficial uses of the receiving water body. WQMA stakeholders must also identify the necessary control measures to institute and effectively achieve the water quality program objectives or improvements.

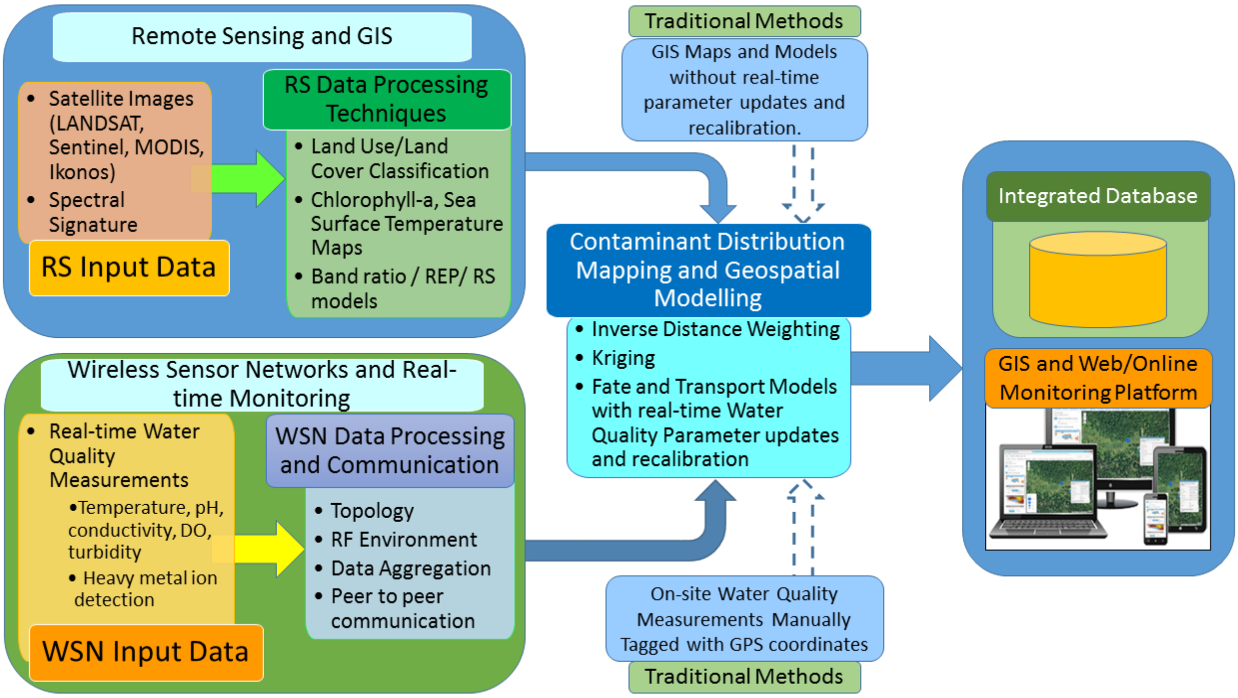

Fig. 1: An integrated framework for environmental monitoring employing RS, GIS, WSN and RE technologies.

There are sixteen (16) regional offices of EMB that performs the regulatory functions such as permitting, review of environmental impact statements, compliance monitoring, and inspection. Through these regional offices, the water quality monitoring (WQM) program of EMB-DENR is implemented. Water bodies were assessed based on the number of samples meeting the DAO 1990-34 water quality criteria per parameter and each parameter was monitored quarterly. Of the 688 water bodies identified by the DENR, only 199 or approximately 29% are regularly monitored from year 2006 to 2013. Their WQM programs collect data on physico-chemical and biological analysis from either water samples or using portable on-site monitoring equipment based on the thirty-three (33) parameters that define the desired water quality per water body classification set in the DAO1990-34 (Environmental Management Bureau 2014).

The recent DAO 2016-08 repealed the old Rules and Regulations of the National Pollution Control Commission (1978), the 1982 Effluent Regulations, and DAO 1990-34, while DAO 1990-35 was modified. However, it is not only the Water Quality Guidelines and Guidelines for Effluent Standards that should be considered but also the water quality criteria. Helmer et al. (1997) pointed out that scientists developed water quality criteria that provide the basic information about the effects of water pollutants on a specific water use and the water quality requirements for protecting and maintaining an individual use. These are based on the characteristics of the water and the quality of the suspended particles, bottom sediment, and the biota. Furthermore, the water quality criteria established a number of traditional water quality variables like pH, dissolved oxygen, biochemical oxygen demands for the periods of five or seven days (BOD5 and BOD7), chemical oxygen demand (COD) and nutrients. These criteria serve as guidance especially those countries with rivers affected by organic pollution, low BOD and COD levels like in the case study on the Philippines' Pasig River (Helmer et al. 1997).

Technologies employed in water quality monitoring: The approved methods of analysis being prescribed by the EMB is based on the "Standard Method for the Examination of Water and Wastewater" which was published jointly by the American Public Health Association, the American Waterworks Association and the Water Pollution Control Federation of the United States. Atomic Absorption Spectrophotometry (AAS), for example, is the approved method for analysing parameters like cadmium, lead and total mercury. Table 1 shows the approved methods of analysis for each parameter for water quality assessment.

The DENR also employs various measurement and modelling techniques through the conduct of various case stud-

Table 1: The approved method of analysis for water quality assessment (DAO 1990-35).

Parameter	Method of analysis
Color	Visual comparison method platinum cobalt scale
pH	Glass electrode method
Temperature	Use of mercury-filled thermometer
BOD	Azide modification (Dilution technique)
Dissolved Oxygen	Azide modification (Winkler Method), Membrane electrode (DO meter)
TSS	Gravimetric method
PCB	Gas chromatography (ECD)
Chlorinated Hydrocarbons	Gas chromatography (ECD)
Boron	Carmine method (Colorimetric method)
Cyanide	Specific ion electrode method
Oil and Grease	Gravimetric method (Petroleum ether extraction)
Fecal Coliform	Multiple-tube fermentation technique or membrane filter
Total Coliform	Multiple-tube fermentation technique or membrane filter
Arsenic	Silver diethyldithiocarbamate method (Colorimetric)
Lead	Atomic absorption spectrophotometry (AAS)
Cadmium	AAS (Wet ashing with concentration HNO3 + HCl)
Total Mercury	Cold vapor technique, (Mercury Analyzer, AAS)
Nitrate as Nitrogen	Brucine method for saline waters, specific ion electrode meter for fresh water
Chromium	Diphenyl carbazine colorimetric method

ies with the aid of international organizations in monitoring the water quality in the country to be able to establish the degree of pollution and overall conditions of its major rivers. With the technical assistance from International Development Agency, the DENR monitored the water quality of Pasig River between 1989 and 1990 with bi-monthly measurements taken from ten (10) samples to assess the level of pollution (based on BOD, DO, coliform bacteria counts, salinity, phosphate and nitrates) using the Mike 11 system model (World Health Organization 1997).

To boost the water quality monitoring and assessment in a regional level, a tri-sector approach involving public, private and academic sectors was recently initiated through the implementation of the Sensing the Environment Parameters using Telemetry (SENTRY) Project in Region 4A CALABARZON. This multi-sectoral collaboration was forged by DENR regional office (Region 4A) with other regional offices like the EMB, Bureau of Fisheries and Aquatic Resources (BFAR), and Department of Science and Technology (DOST), the local government unit (LGU), the non-stock non-profit Pusod, Inc. organization, and the Batangas State University (BSU) who led the design and fabrication of water quality monitoring systems. The BSU developed devices for real-time automated data acquisition to help avoid fish kills and other adverse effects of poor water quality (Department of Science and Technology 2015). These devices are sensors, developed using information-communications-technology enhanced remote sensing protocol, installed in a catamaran-type buoys to gather data on the water's acidity, turbidity and total suspended solids or particles larger than two microns (Department of Science and Technology Region 4A 2015; Department of Science and Technology 2015). Aside from collecting real-time water quality data, the SENTRY devices can warn concerned agencies whenever the system detects data that are nearing its critical value and can send data to regulating agencies like the EMB-DENR. The first deployment of SENTRY was in Lipote River of Batangas in November 2015 and plans to replicate the system and deployment in other parts of the region was already reported.

Water Quality Monitoring Challenges

Challenges being faced by the Philippine government lye on the problems associated with the absence of clear responsibilities, with the overlapping of institutional boundaries, duplication of work and a lack of coordination between involved institutions. These are also common obstacles to effective water pollution control in many countries (Helmer et al. 1997). The enactment of the Clean Water Act of 2004 is recognized as the dramatic shift in water quality management in the Philippines (JICA/DENR-EMB 2010), however, the enforcement of the law through the water quality monitoring guidelines and even the implementation of most of the law's environmental regulation aspects is still at the developing stage (Japitana et al. 2016). Depending on available laboratory facility, instruments, transport and human resources, all water quality monitoring programs of the country are restricted in some ways and may collect data primarily by direct sampling or limited water quality parameters. Also, not all regional offices (ROs) with active mining operations and other related industrial sectors have the capability to monitor regularly the levels of heavy metals in the water bodies. Furthermore, the Philippines has no large-scale treatment and disposal facilities for hazardous wastes (National Economic and Development Authority 2011). All of these, are due mainly to the government agencies' lack of budget, experience, and expertise on national policies and its requirements and provisions ldescribed in the CWA (JICA/DENR-EMB, 2010).

Republic Act 9275 or the CWA mandates the DENR, through EMB, to be the national authority responsible for pollution prevention and control, and environmental impact assessment (Environmental Management Bureau, 2014). With regards to implementing this law, though the EMB has 16 regional offices installed nationwide, not all regions are fully equipped to carry out the complete water quality monitoring procedures. This problem was initially addressed through a technical cooperation project between JICA and EMB that was implemented from 2006-2011 with the capacity building of EMB in their mandates under CWA implementing rules and guidelines as one of the main goals. The technical cooperation project aims to provide EMB with an adequate understanding of the WQM procedures in conformity with CWA requirements. Three pilot ROs were intensively trained and the capacity of non-pilot ROs were strengthened through participation in the learning process and in activities such as orientation/workshop (JICA/DENR-EMB 2010).

Another challenge is the absence of a complete, accurate and up-to-date data monitoring system which can provide basis for analysis and decision-making and offers accessibility and full participation by stakeholders to guarantee transparency and accountability (La Vina et al. 2012).

Surface Water Quality in the Philippines

Physico-chemical parameters: The key water quality parameter used by the EMB in the monitoring of surface waters is the dissolved oxygen (DO) and other water quality parameters, depending on the beneficial usage and potential pollution sources of the water body. This includes BOD, total suspended solids (TSS), phosphates, nitrates, heavy metals, free cyanide, and faecal coliform (FC), and total coliform (TC) (Environmental Management Bureau 2014). Their monitoring results from 2006 to 2013 were published in the 2014 National Water Quality Status (NWQS) report. In the NWQS Report of the EMB, results showed that only 42 percent of the inland surface waters that were monitored regularly passed the criteria for DO and BOD. While for the 40 water bodies that served as sources of drinking water being monitored by EMB, only 28 percent conformed to the criterion for TSS, signifying the effects of sand and gravel quarrying activities and runoff sediments from denuded forests and agricultural lands. Moreover, only 27 percent of those monitored for both phosphates and nitrates were fully compliant with their corresponding criteria (Environmental Management Bureau 2014).

Heavy metals: Water bodies monitored for heavy metals like mercury, lead and cadmium are limited and focused only on those areas with remarkably known sources of these pollutants (Environmental Management Bureau 2014). EMB reported that heavy metals are monitored in areas that are in close proximity to mining, electroplating, tanning, and other similar activities. In the NWQS report of the EMB, 14 out of 18 or about 78% of the monitored rivers for total mercury exhibited 100 percent compliance to the maximum limit of 2 micrograms per litre (μg/L). The four rivers exceeding the mercury criterion are Agno, Panique, Tubay and Malaguit. For Agno and Panique-rivers, both exceeded the criterion in only one sampling event reaching an average mercury concentration of 4.3 μg/L and 430 μg/L, respectively. Likewise, Tubay River did not meet the criterion in two sampling events with an average concentration of 2.5 μg/L in both instances. While Malaguit River has failed to meet the criterion in six sampling events, with an average concentrations from as low as 3 μg/L to as high as 9 μg/L. With the noted exceedance of mercury in Agno and Tubay rivers, both classified as Class A, their use as source of potable water could be detrimental (Environmental Management Bureau 2014).

There are 18 water bodies monitored for cadmium according to the NWQS report of the EMB. Ten out of 18 rivers being monitored were reported to show deviations to the criterion with exceedances ranging from as low as 0.011 mg/L to as high as 0.108 mg/L, with a median value of 0.014 mg/L. Agno river, together with two other Class A rivers (Chico and Balili) had the lowest compliance ratings for cadmium. The lowest compliance rating of 9% was surprisingly that of a priority river, the Balili River with only 9% compliance to the criterion. Whereas, Agno River and the upper reach of Chico River had compliance ratings of 48 percent and 46 percent, respectively. Moreover, in the same report, there are 11 out of 18 water bodies monitored for lead which showed exceedances to the criterion. Five of these rivers have average lead concentrations ranging from 0.06 to an alarming level of 0.58 mg/L and with compliance rating ranging from 44% for Chico River to 73% for Amburayan River (Environmental Management Bureau 2014).

ADVANCED TOOLS FOR ENVIRONMENTAL MONITORING

Contamination Detection

Remote sensing-based modelling and estimation: Land use information is important in many applications, i.e., tax assessment, urban planning, and environmental management (Park & Stenstrom 2008). Kibena et al. (2014), for example, investigated land use changes derived from analysing multispectral satellite images to assess its impact to the water quality of a river that drains to a rural and urbanized part of the catchment. The works of Dlamini et al. (2016) also proved the use of satellite images to investigate the effect of land use changes within a catchment to identify pollution sources.

Multi-spectral remote sensing is superior because more information could be provided to help identify a number of similar objects. Modelling using multi-spectral images require analysis of the correlation between bands to be able to distinguish the sensitive bands that will best describe the water components' spectral characteristics (Liu et al. 2010). In this way, the concentration of any contaminant or of a water quality parameter can be detected using satellite images as an alternative measurement tool. Almost all researches employing remote sensing are about dissolved organic matter and chemical oxygen demand (Dong et al. 2015). These water quality parameters in remote sensing images need data inversion model. In particular, the remote sensing datasets mostly used in studies related to oceanography and water quality monitoring are those from Sea-viewing Wide Field-of-view Sensor (SeaWiFS), Moderate Resolution Imaging Spectroradiometer sensors (MODIS), Ocean Colour Monitor: OceanSAT, and Landsat series (Kibena et al. 2014). Remote sensing images need data inversion model for preprocessing, extracting the intuitive thresholds to reflect water quality (Liu et al. 2010). Some examples in the literature demonstrating remote sensing-based modelling of water quality parameters are for chlorophyll-*a* (Dlamini et al. 2016, Nazeer & Nichol 2016, Yunus et al. 2015), total suspended matters (Dekker et al. 2001), turbidity (Dong et al. 2015), radiant temperatures (Wilson et al. 2003), and heavy metals (Schwartz & Ben-Dor 2011, Shi et al. 2014).

Spectroscopy and analysis: In spectroscopy, the absorption bands within 400-2500 nm range are very important for the identification of the minerals which have the absorbing physicochemical structure of photon, but it is in the visible near infrared region of the spectrum where absorption is caused by transition metals like lead, manganese and copper (Gannouni et al. 2012). Vegetation (Clevers et al. 2004), soil (Gannouni et al. 2012, Shamsoddini et al. 2014) and ore samples, and stream sediments (Choe et al. 2008) are the most often mediums analysed for spectroscopy. Spectral signatures can be derived by laboratory reflectance spectroscopy (Gannouni et al. 2012) and on-site measurements (Choe et al. 2008). The popularity of Vis-NIR spectrometers in soil science is due to its portable format, easy and ready to use in the field, and require minimal or even no sample preparation (Horta et al. 2015). Among the modelling techniques employed to identify correlation between spectral data and heavy metals concentration on soils and stream sediments are the First Derivatives of the reflectance data (Shamsoddini et al. 2014, Clevers et al. 2004), band ratios (Choe et al. 2008), continuum-removal and band-depth (CR-BD) analysis (Choe et al. 2008), and Partial Least Square Regression (PLSR)(Gannouni et al. 2012).

For water quality monitoring, a growing number of researchers have used different types of spectrometers, combined with varying methods of measurement to obtain the spectral data of a water body (Liu et al. 2010). The physics and chemical characteristics of water can be determined from spectral signatures; this method however can only provide low accuracy and it is hard to perform real-time monitoring (Jiang et al. 2009). On the other hand, Liu et al. (2010) pointed out that the interaction between water components and spectra can be considered as a very complex non-linear relationship which requires application of mathematical modelling methods in order to build analysis, simulation, and quantitative inverse relation in different water bodies or the same body of water in different time frames.

Analysis using WSN sensors, instrumentation and field monitoring: The wide area of applications of marine environmental monitoring covers marine product contamination monitoring (Daokun et al. 2010), marine habitat monitoring (Szewczyk et al. 2004) and other related topics including heavy metals monitoring (Zhuiykov 2012). The detection of pollutants consists of a variety of monitoring and analysis strategies that, depending on the level of comprehensiveness, may vary in cost and instrument requirements (Altenburger et al. 2015). The conventional water monitoring campaigns, both *in-situ* and off-line measurements, usually require technical experts and divers, water vessels, and expensive instruments like commercial probes, data loggers, and improvised sensors and platforms.

Off-line detection of contaminants often does not provide the required spatial discrimination and/or the large sets of data necessary to describe the temporal evolution of the parameters of interest, hence, on-site measurements or inline analysis are being conducted as an alternative approach in order to gather water quality data at the location of interest (Capella et al. 2010). According to Capella et al. (2010) the major advantages of inline analysis over the classical off-line procedures are the following: (a) elimination of contaminants due to sample handling, i.e., no or minimum sample transformation; (b) minimization of the overall cost of data acquisition (in particular, due to a reduction of time for sampling, handling and analysis of the sample);

(c) possibility of real-time analysis, allowing the rapid detection of pollutants (e.g., monitoring of industrial wastewater or water quality in water treatment plants); (d) ability to obtain detailed spatial and temporal data sets of complete ecosystems (lakes, aquifers, etc.), and (e) possibility of performing measurements in locations which are difficult to access (deep lakes or oceans).

There has been various efforts to improve the instrumentation for inline water monitoring in order to achieve precise, periodic and near real-time data acquisition of the parameters of interest. The focus of water quality monitoring is to have a real-time *in-situ* water quality data of parameters like pH, DO, temperature, turbidity, and conductivity (Yue & Ying 2012) and water conditions like colour, wind speed, and direction. One of the promising efforts nowadays pertains to Wireless Sensor Network (WSN) which was developed due to the progress of wireless communication and embedded micro-sensing using micro electro mechanical systems (MEMS) wherein, number of autonomous sensors are working collaboratively to monitor parameters of interest (Yick et al. 2008). WSN technologies were already employed in rivers, bays, lakes, seashore and other aqueous places (Jiang et al. 2009). Environmental monitoring using WSN in the wide areas of coverage has corresponding requirements for modalities, technologies like sensing (Estrin et al. 2001), communication (Rasin & Abdullah 2009), floatation (Pérez et al. 2011); and its architectures (Karl & Willig 2006).

The WSN's features such as lower energy requirement, cheaper electronic devices that are able to carry out data acquisition tasks, data that are then processed and transmitted to a process center for their storage and further analysis makes this technology more advantageous (Capella et al. 2010) compared to the traditional water monitoring devices and strategies. Moreover, WSN technology gives an advantage of fast deployment of wireless sensor node in a remote area where the pollution level can be monitored at low cost and without expensive infrastructure (Chung & Yoo 2015). Capella et al. (2010) also emphasized that the new advances in the field of transducers like the ion selective sensors (ISEs) allow for the detection and measurements of chemical and physical properties easily and inexpensively. In the literature, success has been shown in line with the feasibility of using WSN and solar harvesting technologies in water quality monitoring, however, most of the developed systems are focused on measuring physico-chemical parameters as given in Table 2.

Study on WSN-based heavy metal monitoring is increasingly popular but is confronted with the problem of the need of highly sensitive sensors (Zhuiykov 2012) that can be used to monitor the presence of very small amount of heavy metals. It is also important to note that there are still several challenges in using WSN like resource constraints which include limited energy supplies, limited memory, and computational capacities; dynamic and extreme environment conditions; data redundancy; unreliable wireless communication; no global identification (ID) for sensor nodes; prone to node failure and large-scale deployment (Rawat et al. 2013).

In a WSN-based environment monitoring system, its main purpose is commonly for data collection from the environment where regular access is not possible or impractical (Ferdous et al. 2016) or very costly. Since sensors are powered by batteries, issues on its limited lifespan (Nallusamy & Duraiswamy 2011) and the need to replace them periodically is a challenge. This has opened the research field for renewable energy (RE) in application to power management and efficiency of WSN monitoring systems. Various efforts to address this challenge were focused on solar photovoltaic systems as one of the solutions. Utilizing solar power in WSN in establishing the topology where node can receive and transmit pocket without consuming the limited battery resource becomes a consideration (Nallusamy & Duraiswamy 2011). Voigt et al. (2003) presented that the solar cell can be used to power up sensor and to charge the batteries during the idle period of nodes, the stored battery energy can be used to power the nodes during the absence of sunlight which the solar-rich nodes can take over the responsibility of relaying data to the base station. Moreover, their research proves that the solar power method results in energy saving resulted to a sustained lifetime network and better performance of the system.

Examples include the solar-powered water quality monitoring system using wireless sensor networks (Amruta & Satish 2013) that is deployed in a remote area where power supply is one of the issues in the operation. Their system utilized the solar panel together with the battery to recharge when the solar power is not enough especially in the evening. Also, the works of Polastre et al. (2005) demonstrated a longer duration solar power subsystem for mote-Telos which is a WSN system. Another area of concern is the challenge in monitoring water quality in a wider area of coverage and deployment of monitoring systems in remote areas and narrow water bodies. This gave way to various proposed monitoring systems by employing small surface water vessels equipped with sensors. An example of fusing solar technology and WSN was applied to develop a solar powered autonomous surface vessel (SPASV) which is capable of navigating throughout the inland water and measure a range of water quality properties and greenhouse gas emission. The

Table 2: Examples of WSN-based water quality monitoring systems.

Author/Year	Parameters Measured	Features/description of the WSN-based monitoring system
(Amruta & Satish 2013)	pH, turbidity, oxygen level	Data collected from different sensors at the remote site can be displayed in visual format as well as it can be analysed using various simulation tools at base station. The system has no carbonemission, low power consumption, and more flexible to deploy at remote site
(He & Zhang 2012)	pH, conductivity, dissolved oxygen	A low-cost and simple WSN-based water quality monitoring temperature, turbidity system which works in a mesh network. The system is always in the standby mode until the off-chip RTC wake the nodes up allowing low power consumption.
(Ritter et al. 2014)	Temperature, pH, DO, electrical conductivity	Device has delay-tolerant feature which allows users to collect the data when it is most convenient for them instead of having to collect data regularly. In case of disruption in energy supply, the data is still present from all previous measurements for the user to obtain.
(Faustine et al. 2014)	Temperature, DO, pH, electrical conductivity	A low-cost water quality monitoring system that provides soft conductivity ware module that allow users to visualize the data (in graphical and tabular form) from the WSN without installing specific software.
(Tuna & Gulez 2013)	Temperature, pH, DO, conductivity, turbidity, nitrate	Two-way approaches for low-cost and portable water quality monitoring system consists of an autonomous boat loaded with probes and WSN-based buoys. Probes on the boat collect and log water quality data during missions while probes mounted on buoys deployed at fixed positions regularly analyse and transmit data to the control center.
(Sun & Sun 2016)	Temperature, DO, pH	The system has a solar-powered data logger that collect real time and *in-situ* data at fine temporal granularities to monitor water quality. The system also contains a GSM/GPRS modem for sending collected data to a cloud platform.
(Curiel & Ramirez Zigbee 2016)	pH, temperature	A low-cost on-site monitoring floating structure using a protocol that support mesh networks and has capability for self-discovering and reconfiguration in case a node leaves the network, allowing transfer of data from nodes to a nearby station for continuous processing.

16 feet long solar powered vessel collects various water quality information, as well as measuring the spatial-temporal release of various greenhouse gas emissions through the water column while moving, the unique feature of this SPASV is its integration into storage scale floating sensor network to allow mission upload, data downloading and adaptive sampling strategies (Dunbabin et al. 2009).

Contaminant Distribution Mapping and Modelling

Scientific findings towards understanding contamination and long-term land use relationships are highly effective and valuable in order to identify potential mitigation and control measures. This could be made possible by using remote sensing imaging techniques to monitor upstream land use and land cover changes and spread (Kibena et al. 2014) and Geographic Information Systems (GIS) as a tool to map the spatial distribution of contaminants in order to clarify pollution history (Zhou et al. 2007) and have a good basis of pollution evaluation and risk control (Xie et al. 2011). Remote sensing offers synoptic, repetitive, consistent, cost-effective, and comprehensive spatio-temporal views (Kibena et al. 2014) that raised much advantage and necessity in employing this technology in monitoring water quality status of larger water bodies.

While remote sensing technologies fill the inadequacy of information in point-based water quality assessment studies, GIS on the other hand, evolved as a unique tool for geostatistical analysis and spatial interpolation utilizing measured samples with known values to estimate unknown values so as to visualize the pollution spatial patterns (Yan et al. 2015). Japitana et al. (2016) cited that by employing interpolation techniques in GIS, contamination data and other attributes of a point vector layer can be converted into a continuous surface to generate distribution maps of a certain contaminant. Some of the spatial interpolation tools widely used for this purpose are Inverse Distance Weighting (Elbana et al. 2013, Matejicek et al. 2006) and ordinary kriging (Yan et al. 2015, Matejicek et al. 2006). Interpolation techniques for predicting soil heavy metals were compared by Xie et al. (2011) where they pointed out that all interpolation methods provided a high prediction accuracy of the mean concentration, but the spatial uncertainty of polluted areas was mainly located in three types of interpolated region, namely: (a) the local maxima concentration region surrounded by low concentration (clean) sites, (b) the local minima concentration region surrounded with highly polluted samples; and (c) the boundaries of the contaminated areas.

Inverse distance weighting (IDW) is one of the most straightforward and most practical interpolation methods used for soil and coastal waters (Zhou et al. 2007), which is based on the assumption that measurements that are closer together tend to be more alike than those that are farther apart, making the surface estimation of sample data statistically meaningful (Schroder 2006). For monitoring heavy metals in particular, IDW was employed to determine pollution distribution (Borges et al. 2014), pollution patterns (Zhou et al. 2007) and hotspots.

Kriging is another geostatistics tool used by many environmental monitoring studies. Among the kriging methods, ordinary kriging is a simple prediction method with remarkable flexibility (Environmental Systems Research Institute (ESRI) 2012). To estimate the spatial distribution of heavy metals and determine the highly contaminated area of the lake being monitored, a sample study employed the ordinary kriging method (El-Amier et al. 2017). Similar accuracies were obtained by Khalil et al. (2014) in considering both ordinary kriging and simple kriging in their study on assessing the environmental impact of abandoned mines and forecasting how pollution occurred. In the end, they adopted the simple kriging technique for elaborating spatial pollution variation maps.

Water Quality Data Management and Dissemination

An integrated platform that provides a good visualization and analysis of a comprehensive water quality data is always hoped to achieve and to allow the intended users to immediately evaluate the marine environmental conditions and its underlying factors. From there, intended users can formulate the appropriate course of actions for mitigation and rehabilitation of the affected water body. This ideal setup describes a complex environmental modelling method that requires the integration of multi-disciplinary data collections from government agencies and private institutions like hydrological models at various watershed scales, land use maps and satellite images, GIS-derived maps, laboratory and WSN-based water quality datasets, geotagged photographs and video recordings, and reports in various formats.

There were already numerous studies integrating various datasets, but they, however, do not reflect the ideal setup for water quality monitoring. Peng et al. (2011) introduced an attempt to develop a water quality database selected objectively from a wide array of recent and historical datasets to reflect the water quality of a lake. The proposed method of Peng et al. (2011) demonstrates the possibility of building a database that integrates water quality data from the environmental monitoring department of the government and recent research works from relevant research institutes. Also, an extended framework of a solar-powered WSN-based environmental monitoring was presented by Alippi et al. (2011) which involves sensing activity, local and remote transmission, and real-time data storage and visualization. A complete visualization facility on the web that is considered to be relevant and useful in water quality monitoring include features such as: 1) data displays in an organized tabular form that allows exporting in spreadsheet or other formats; 2) data are supported with photographs or graphical plots (Oliveira et al. 2014); 3) interactive data display and plotting capabilities with hovering effects, pan and zoom options, and allows exporting of the plots in image format; 4) interactive map rendering that allow users to overlay map layers, pan, zoom, and select features or objects on the web page (Swain et al. 2016). With this kind of interactive and integrated platform for water quality monitoring, a wide range of users (professional and non-professional, technical and non-technical) who are non-GIS users can optimize and exploit the available data and information being disseminated on the web for decision making and/or further research works.

The recent advances in GIS and web technology provide the opportunity for the development of an on-line, centralized, and comprehensive data platform with interactive visualization utilities for the environmental community and decision makers. Moreover, a long list of free and open source software (FOSS) is available nowadays for web application development to provide a database and simulation platform (Swain et al. 2015). Swain et al. (2016) presented various web applications that demonstrate the use of open source platforms that they further commended for lowering the barrier for developing environmental web applications.

FUTURE PERSPECTIVE

The literature offers a wide array of possible and appropriate technologies for low cost water quality monitoring using remote sensing, GIS, wireless sensor network, and renewable energy technologies. Remote sensing and GIS techniques that can empirically estimate contamination or water quality indicators and in identifying causal effects of anthropogenic activities were cited in this review. Moreover, the freely available remote sensing data do not only provide an alternative source of water quality data, but also aid the need for a temporal data collection at a minimal cost. GIS and web technologies, on the other hand, can also address the need for a comprehensive database for water resource and water quality monitoring. A long list of free and open-source software for database management and webmapping is available where making these RS and GIS-derived models and maps accessible to agencies and the public can offer a new wave of evaluating the environmental situation and promote transparency. It should also be considered, that there is a rapid increase in the amount of relevant data from research institutions, scientists, and environmental practitioners from the private sector. Incorporating these to the government water quality database will not only build a rich database (of recent and historical data) but could also save time and financial resources.

Another alternative and recent technology for environmental monitoring that the country should consider is the use of wireless sensor networks. Further, the country should consider maximizing its known advantages like easy deployment of sensors, real-time monitoring, and cost-efficient operation. Deploying WSN-based sensors in remote and difficult to access areas improves the spatial distribution of sampling points along the whole stretch of the water body being monitored. It also provides security and safety of personnel and savings in terms of budget. Although energy sources for long-term deployment is one of the known limitations of WSN-based monitoring, it gives an opportunity to explore the advantages of renewable energy (RE) technologies in the Philippines. Mainly because energy harvesting materials and ready-to-use systems are becoming more available and cheaper, and the country is geographically located near the equator. The utilization of RE technologies ranges from powering up sensor nodes to supplying adequate energy for base stations that will allow continuous data acquisition for a considerable period of time.

Environmental studies and monitoring involves a repetitive process of sampling of the environment during certain period of time. The high temporal frequency of data collection allows researchers to regularly update model parameters which can then increase the accuracy of the models. Hence, we propose an integrated water quality monitoring framework as shown in Fig. 1 which combines the paradigm of remote sensing and GIS with that of wireless sensor networks and real-time monitoring. In the past, traditional methods of contaminant distribution mapping and geospatial modelling use historical data of on-site water quality measurements and processed satellite images. A problem with the traditional methods is that satellite data and on-site measurements do not match temporally. In the proposed framework, processed satellite data can be synced with the real-time information coming from wireless water quality sensors.

The framework as shown in Fig. 1 utilizes results from processed RS data such as land classification maps, chlorophyll-*a* maps, and surface water temperature maps. These RS data are incorporated into geospatial models and algorithms such as inverse distance weighting and kriging to produce contaminant distribution maps. These models, however, would be updated and recalibrated using real-time water quality measurements like temperature, pH, DO, turbidity and heavy metal concentration. This process of temporally syncing data from the two paradigms, namely; water quality inference from satellite images and real-time on-site water quality measurements, can produce a substantially more accurate water quality map.

On-site measurements of spectral response of water and WSN-based water quality at permanent sampling points can also be initiated as additional task for the conventional environmental monitoring campaigns. Mathematical models can then be derived by analysing substantial on-site spectral data combined with water quality data derived from WSN-based sensors and traditional methods (on-site and laboratory analysis). These mathematical models can then be applied for satellite image analysis to derive water quality maps per parameter. Also, land use and land cover information delineated from the satellite images can aid in identifying the factors affecting water quality. Aside from identifying hot spot areas, scenario modelling (e.g., simulating changes in land use and land topography, water quality data, etc.) and spatial analysis within a GIS platform can help in mitigating possible contamination. Moreover, the visualization of map layers and spatial analysis provides an efficient way of evaluating basic but important aspect in environmental monitoring which includes 1. Distribution and statistical strength of existing sampling points; 2. Identification of areas where water quality values are fluctuating and unstable; and 3) Locating new sampling points that can better reflect the water quality of a catchment.

For an integrated and interactive water quality monitoring platform, all data gathered from field measurements (photos and videos, spectral data, WSN-based water quality data, and water quality data derived from conventional method), water quality data from laboratory analysis, hydrological models, RSGIS-based models, and GIS vectors and raster datasets must be organized in an on-line database for data display and visualization using web technologies. Through this web platform, real-time monitoring for private and government agencies can be realized with the deployment of WSN-based sensors in which water quality data are transmitted via Global System for Mobile Communication (GSM) network to the base station. Also, mechanisms for sending notifications via e-mails and/or SMS are available to warn authorized personnel whenever the water quality values detected are nearing or exceeds the critical limits. This will allow formulation of immediate plans and actions to mitigate water contamination problems. On the other hand, we wish to emphasize that end-users may not always be familiar with the web or phone-based platform for water quality monitoring. Hence, we further propose that the integrated and comprehensive online platform must be a user-friendly interface that will guide all type of users.

CONCLUSIONS

The main purpose of this review work is to identify underlying challenges in water quality monitoring in the water bodies of the Philippines and the prospective tools that can be most appropriately used in the locality, and their integration in the assessment, management and rehabilitation of contaminated water bodies. Here, we presented established and emerging technologies that can be employed for cost-effective and a wider spatial and temporal scale of water quality monitoring. Most of the technologies discussed in this review are low cost, but require training and capability building to acquire the theoretical and technical know-how in implementing them. We would like to emphasize though that the application of an integrated system of RS-GIS mapping and modelling and the WSN-based sensors is introduced to augment the existing traditional methods. These technologies are aimed to address the challenges in implementing WQM programs of the government, namely: expensive equipment and instruments for WQM, insufficient resources, sampling frequency and distribution, and power requirement for periodic or continuous water quality data logging. It is also important to note that even if these methods are effective and promising, their strength can still be pulled down by the limited technical expertise, openness of personnel to employ new techniques, and accessibility and availability of auxiliary technologies such as internet and transmission networks.

The integration of these alternative technologies therefore gives an opportunity for a complete and comprehensive water quality monitoring despite limited budget and resources. The techniques being proposed combined with the conventional method helps to lessen the cost and ease the work in environmental monitoring without compromising sampling frequency and distribution. With energy harvesting system installed to WSN-sensors, especially those deployed in remote areas, a continuous water quality data acquisition can be anticipated with lower maintenance and travel cost. Free and downloadable satellite images analysed and processed using free and open source RS-GIS software offers a wide opportunity for environmental modelling and simulations that can aid in the assessment, management, and rehabilitation of water bodies. Lastly, by employing free and open source web technologies, a comprehensive and interactive platform for data display and dissemination that can provide valuable and timely information for an informed decision-making of various stakeholders.

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