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ORIGINAL RESEARCH ARTICLE

SPACE TECHNOLOGY APPLICATIONS FOR WATER QUALITY IN SUSTAINABLE DEVELOPMENT

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ABSTRACT

Water is one of the most important elements for sustaining-life. Despite water's abundance, good quality water is available in a very limited quantity. Water quality describes water's condition, including physical, chemical, biological and radiological-characteristics, usually with respect to its suitability for a particular purpose such as drinking, swimming and irrigation. Many factors can reduce quality of water such as water-pollution which is the contamination of water-bodies, usually resulting from human-activities. Poor water quality poses a health-risk for people and ecosystems. Water quality is measured by several factors, examples of which are the dissolved-oxygen, salinity, turbidity, pH, temperature. Water quality is a complex issue and requires large amounts of diverse accurate data in a timely manner. Collection of water quality measurement data by traditional method can be quite difficult and resource intensive especially in the remote-areas. Therefore, there is a need to supplement the traditional method of ground-based monitoring with space technology especially satellite-based monitoring that provides better effective means of data-collection. Satellite-based monitoring is helpful in attaining sustainable development, which includes economic-growth, environmental-protection and social-equality; in-line with the Sustainable Development Goal "Clean Water and Sanitation" of the United-Nations. Space technology applications for water quality has several advantages including large area coverage, measurement-frequency, effective up-to-date, cost-effective and in time manner. This paper reviews space technology's use in water quality assessment to achieve sustainable development. Examples of space technology spin-offs and use of on-line open data-access on water quality monitoring are discussed. It also proposes satellite technology viewing few millimeters contaminants in water-bodies in the nearest-future.

1.0 Introduction

Water is inevitable as a result of the various uses such as for: drinking and cooking (as portable water), agriculture (for example for irrigation and watering stock), games and recreation, healthy aquatic ecosystems (for example in fishing), wildlife habitats, navigation and shipping, industrial processes, scientific study and education, meeting cultural and spiritual needs. These make water the second most important element for sustaining life on the Earth, other than air (Harinder, 2018). Despite being apparently in abundance, good quality water is available in a very limited quantity. Figure 1 shows the global water bodies and land.

Figure 1: Global Water Bodies and Land. Image Source: ESA CCI (2019).
Key: Blue colour is water; White colour is land

Water quality describes the condition of water, including physical, chemical, biological and radiological characteristics, usually with respect to its suitability for a particular purpose such as drinking, swimming and irrigation (NOAA, 2018). This is an aspect of water security that encompasses water management and water quality. Water security is the reliable availability of adequate quantity and acceptable quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks (ESA, 2018).

This paper is a review of how space technology is used for water quality assessment as a means to sustainable development. Specific examples of related space technology spin-offs and the use of space technology derived open data-access from specific websites on water quality monitoring are also discussed. This article also proposes that in the nearest future, satellite technology will to be able to view few millimeters contaminants in water-bodies.

2.0 Quality of Water

Although scientific measurements are used to define water quality, it is not a simple thing to say “that water is good” or “that water is bad”. So, the determination is typically made relative to the purpose of the water. Is it for drinking or to wash a car with or for some other purpose? The quality of water is reduced majorly by pollution. Water pollution is the contamination of water-bodies, usually as a result of human activities. Poor water quality poses a health-risk for people and ecosystems (NOAA, 2018).

2.1 Water quality Measurement

Water quality measurement involves analysis and integration of large volume of data (Raj et al., 2011). Water quality is measured by several factors or indicators. These indicators are classified under the following characteristics (NOAA, 2018).

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Physical characteristics: Such as odour, colour, taste, temperature, total suspended solids (TSS), transparency or turbidity and total dissolved solids (TDS).

Chemical characteristics: Such as pH, dissolved oxygen (DO), total hardness (TH), heavy metals, nitrate, orthophosphates and pesticides.

Biological characteristics: Such as Mollusca, E.coli and Coliform bacteria.

Radiological characteristics.

2.1.1 Ground-Based Water Quality Measurement

Water quality measurement is a very complex issue and it requires large amounts of diverse accurate data in a timely manner. Collection of data by traditional means (for example field work) can be quite difficult at times, especially in remote-areas, as well as costly and resource intensive (Harinder, 2018).

2.1.2 Space-Based Water Quality Measurement

Many organizations have supplemented their ground-based monitoring with the use of Earth Observation (EO) technologies such as satellite-based monitoring which can be very useful as it can provide a cost-effective means of replacing or complimenting field data-collection (Harinder, 2018). EO data can be integrated with the in-situ collected data for real-time measurement (Harinder, 2018). Space based technologies application for water quality has several advantages including large area-coverage, remote-area coverage, measurement-frequency, systematic, repetitive data capturing, effective up-to-date, and timely predictiveness (Lahne et al., 2015).

Space is the universe beyond Earth's atmosphere. Outer space does not begin at a definite altitude above the Earth's surface. However, the Karman line, an altitude of 100km (62 miles) above the sea level, is conventionally used. Space-based technology are those technologies that came into being, as a result of making space more habitable for astronauts (Oluwafemi, 2019). Space-based technology has allowed findings to novel and efficient ways of dealing with economic, environmental and societal-challenges. Space-based has returned to the Earth as spin-offs with solutions to so many things. Space technology spin-offs are commercial products and services which have been developed with the help of space technology, through research and development (Oluwafemi, 2019).

Satellites are objects that orbit or circle around bigger objects in a space environment (outer space). There are natural and artificial satellites. Artificial satellites are launched into space to do specific jobs. Artificial satellites are launched using rockets (Oluwafemi and Olubiyi, 2019). They are built by Scientists and Engineers and sent into outer space to receive signals and send signals back to the Earth. On Earth, the signal sent by a satellite is received by large radio antennas. Each antenna is a dish and may have a diameter of several meters. Satellite may be classified either by their missions or by weight. When classified by mission there are at least four types. These types are Communication, Meteorological or Weather, Navigation and the Earth Observation (EO) satellites. The Earth Observation satellite may also be called Remote Sensing Satellites. This type of satellite carries sensors/cameras payloads for imaging the Earth surface thus providing information on our environment, like vegetation, soil type, flood, forest, fire (Oluwafemi and Olubiyi, 2019).

GPS (Global Positioning System) uses satellites that orbit Earth to send information to GPS receivers that are on the ground. The information helps people determine their location, while Geographic Information System (GIS) is a computer software program that helps people to use the information that is collected from the GPS satellites. Remote Sensing is the art and science of making measurements of the Earth using sensors on airplanes or satellites. These sensors collect data in the form of images and provide specialized capabilities for manipulating, analyzing, and visualizing those images. Remote sensed imagery is integrated within a GIS. GIS are able to bring large amount of data of both the physical and the social system together in one comprehensive overview shown digitally. Satellite remote sensing is useful by providing navigation, communication and data acquisition (EO) capabilities (Oluwafemi and Olubiyi, 2019).

Therefore, EO technologies such as satellite-based monitoring devices are quite important as space-based water quality measurement systems.

3.0 Sustainable Development Goals (SDGs) and Water Quality

The United-Nations General Assembly in 2015 did set a couple of global goals with the sole objective of transforming the world. These goals are referred to as the Sustainable Development Goals (SDGs) (United-Nations, 2015a). It has been unequivocally demonstrated that water of good quality is crucial to sustainable socio-economic development (Bartram and Balance, 1996). Sustainable development meets the needs of the present, without compromising the ability of future generations to meet their own needs. Sustainable development in an economy includes economic growth, environmental protection and social equality (Oluwafemi, 2019). There are 169 targets for the 17 goals. Each target has between 1 and 3 indicators used to measure progress toward reaching the targets. In total, there are 232 approved indicators that will measure compliance. The goals are (United-Nations, 2015a; United-Nations, 2015b):

Goal 1: Zero poverty
Goal 2: Zero hunger
Goal 3: Good health and well-being
Goal 4: Quality education
Goal 5: Gender equality
Goal 6: Clean water and sanitation
Goal 7: Affordable and clean energy
Goal 8: Decent work and economic growth
Goal 9: Industry innovation and infrastructure
Goal 10: Reduced inequality
Goal 11: Sustainable cities and communities
Goal 12: Responsible consumption and production
Goal 13: Climate action
Goal 14: Life below water
Goal 15: Life on land
Goal 16: Peace and justice strong institutions
Goal 17: Partnership to achieve the goal

The SDG of interest in this paper is the “Goal 6 – Clean Water and Sanitation”. This is to ensure availability and sustainable management of water and sanitation for all. The Sustainable Development Goal Number 6 (SDG6) has eight targets and 11 indicators that will be used to monitor progress toward the targets. The first three targets relate to drinking water supply and sanitation. Worldwide, 6 out of 10 people lack safely managed sanitation services, and 3 out of 10 lack safely managed water services (United-Nations, 2019). Safe drinking water and hygienic toilets protect people from disease and enable societies to be more productive economically (United-Nations, 2019).

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Space technology application stimulates economic growth and improves the quality of life of people (Oluwafemi and Olubiyi, 2019) towards achievement of the SDGs. Space technology through its spin-offs and by-products has made an impact in every aspect of life, from the economic and industrial development to the mini technologies used for terrestrial applications. Space technology has helped in the improvement of information and communications technology, infrastructure, agriculture, education, all these being the basic factors for a sustainable development (Oluwafemi and Olubiyi, 2019).

Space technology applications play a key role in understanding global water cycles, mapping water courses, and monitoring and mitigating the effects of floods and droughts (UNOOSA, 2019). Satellites provide researchers and policy-makers with vital information about the Earth's water system, enabling the prevention or preparedness to response or post-recovery through monitoring, prediction, modelling and implementation of mitigation and adaptation measures (Oluwafemi and Olubiyi, 2018a). Remote Sensing and GIS technology, amongst many other space technologies offer effective and meaningful solutions to the problem of analysis and integration of large volume of data for water quality measurement. The satellite images acquired using Remote Sensing technology provides diagnostic signatures on specific parameters of need such as an indicator of water. Using these signatures, all the needed parameters can be studied and mapped accurately. The synoptic view of the image derived from Remote Sensing technology due to large area coverage, provides information about the parameters on regional scale (Raj et al., 2011).

4.0 Specific Examples of Space Technologies for Water Quality Assessment

4.1 Adequate Water Quality Measurement after Water Disaster

Satellites provide information before and after disaster, as well as ensures timely response to emergencies such as flood, drought, tsunami and hurricane (Lahne et al., 2015). There is now maximization of access through user-friendly mobile technology which provide timely distribution of satellite data necessary to provide warnings within days and seasonal assessments (Lahne et al., 2015).

The free web application such as eoApp, enables anyone with a web browser to view various water quality parameters in a selection of sites across the globe (ESA, 2015). Harinder, (2018) and group of Info-Electronics Systems Inc. (IES) Montreal, Canada have developed a model for an Integrated Disaster Forecasting and Management System (IDFMS). In this model, space-based remote sensing was used for rainfall forecasting, determining accurate Digital Elevation Models (DEM), and flood water cover and after-disaster assessment of water quality.

4.2 Space Technology Spin-Offs in Earth's Market Relating to Water Quality

4.2.1 Total Organic Carbon Analyzer

Total organic carbon analyzer secures safety of water supply. It was developed to monitor the quality of the recycled water supply on-board the International Space Station (ISS). The ISS is a laboratory located just outside the earth where experiments are carried out by astronauts. The total organic carbon analyzer is sophisticated with systems to generate solar electricity, recycle nearly all of its own water, and supply oxygen, as the ISS is an orbiting model of sustainability.

The technology is now commercialized, providing significant cost savings and improved efficiency for water quality monitoring applications—such as helping ensure the security of the Nation's drinking water on Earth (Talbert and Green, 2012). Figure 2 shows total organic carbon analyzer being used on the ISS by an astronaut.

Figure 2: Total Organic Carbon Analyzer Being Used by an Astronaut on the ISS. Image Source: Talbert and Green (2012).

4.2.2 ChemScan Analyzer

Chemscan analyzer is used for monitoring water quality in real time. It was originally designed to provide real time detection of nutrient levels in hydroponic solutions for growing plants in space. Now it's used to monitor treatment processes at water and wastewater facilities around the world (Talbert and Green, 2012).

Growing plants in space presents unique challenges. Using soil may not work due to its weight, the problem of particles floating about in zero gravity, and the potential for harboring health-threatening germs. To address this issue, focus is on developing hydroponic methods of growing plants in space. Hydroponics is the practice of growing plants in nutrient solutions, without true soil (Talbert and Green, 2012).

The hydroponic solutions typically contain a variety of elements that are taken up at different rates by different plants and need to be replenished when their concentrations drop below ideal levels. An analyzer that provides real-time detection of nutrients, organics, and metals in water was developed. That technology, called the ChemScan analyzer, is now manufactured and marketed. In addition to it monitoring the treatment processes at water and wastewater facilities around the world, it helps maintain water quality. This is because water is rarely found in pure form. Water may contain many numbers of contaminants and other chemical and biological constituents that need to be found and removed (Talbert and Green, 2012).

Earlier technology would require water samples to be physically extracted from various points along the treatment process and taken to a lab for analysis—a time consuming and labor-intensive procedure that left significant gaps between measurements. ChemScan's capabilities allow it to automatically draw and analyze samples for ammonia and other nutrient levels, water hardness, or amounts of natural organic matter. ChemScan analyzers require little maintenance or calibration, making them a cost-efficient technology. The sum total of what ChemScan provides is a small fraction of the price that would be required to do the same task with other technologies (Talbert and Green, 2012). Figure 3 shows the picture of a ChemScan Analyzer.

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Figure 3. ChemScan Analyzer, Image Source: Talbert and Green (2012).

4.3 Proposing Satellites to Map Plastics and Microplastics in Polluted Water-Bodies

Recently there have been environmental interests regarding “microplastics”. Microplastics are plastics that are microscopic in size, having less than 5mm in diameter, which emerge mainly from the production of personal care products and fragments of larger plastics by mechanical degradation or by UV light. Microplastics are dumped indirectly and directly into the oceans and are difficult to separate from other organic particles in the sediment. Therefore, microplastics are bioavailable to a range of aquatic organisms (zooplanton) (Oluwafemi and Olubiyi, 2018b).

Ecotoxicological and calcification studies has been explored on the effects of microplastics on marine zooplankton as case studies for effect on human health and the results has being threatening. The effects of plastic debris on marine organisms as a result of ingestion include gut blockages, heightened immune response, loss of lipid reserves, disrupting of other normal physiological functions and other uncertain consequences to the health of the organism. Microplastic itself can move across the food chain and pose significant public health issues to society. It poses potential risk to food insecurity (Oluwafemi and Olubiyi, 2018b).

Space-based technologies, applications and services such as satellite remote sensing through space observations is used for mapping (Bagchi and Bussa, 2011). There is a proposal that in few years to come, this could be used to study plastic and microplastic related pollutions in the oceans (Bouilly, 2014; Oluwafemi and Olubiyi, 2018b, 2018c) for better water quality for the benefit of humankind and the environment. Although, material isolation as a water pollution parameter can be detected using LASER spectrometers as a ground-based remote sensing technique for identification of chemical composition of the water (Bagchi and Bussa, 2011). Bouilly (2014) stated that until today, no one has managed to locate the plastic accumulation zones in water from space.

4.4 Other Examples of the Use of Satellite Technology for Water Quality Monitoring

United States Landsat satellites and French SPOT satellites have been commonly used for water related applications, the introduction of Synthetic Aperture Radar (SAR) based satellites – especially the ones in the last decade with high resolution and dual polarization – have revolutionized the work in water mapping and management, marine surveillance, ice monitoring, disaster management, environmental monitoring and resource management. DEM are being developed to assist in determining water flows and flooding potential. Land cover and land usage mapping, wetland mapping, snow extent mapping and water quality monitoring are the other areas where remote sensing is a great tool (Harinder, 2018).

The National Topographic Database of Natural Resources Canada (NRCan) covers more than 10 million square kilometres. The hydrographic information of the database contains more than 60% of the entities to be updated (Harinder, 2018). The current manual update of this database by visually comparing the vectors of the CanVec Database to SPOT orthoimages is too cumbersome. In 2009, Centre de Recherche Informatique de Montréal (CRIM) issued recommendations to Centre for Topographic Information – Sherbrooke (CTI-S) and developed a prototype for the automatic updating of water-bodies from SPOT-5 imagery (CRIM, 2009). In the second phase, this prototype was improved in order to be integrated in the production process within the CTI-S.

Harinder (2018) and group's project was executed under an Earth Observation Application Development Program (EOADP) contract from Canadian Space Agency (CSA), implements innovative solutions to exploit the capabilities of RADARSAT-2 data for the mapping of water-bodies. IES, in collaboration with the CRIM, has developed a system to improve and update the existing mapping of inland water-bodies as well as find new objects using RADARSAT-2 data in the context of updating the hydrological information within the CanVec database of NRCan. The developed system contains advanced image processing algorithms specifically tuned for optimal performance for an application in water mapping. Due to its high resolution and polarimetric data, the use of SAR imagery provides a more complete and accurate description of the scene compare to the use of SPOT imagery. The system is being tested on data provided by the CTI-S. The use of open source libraries provides with an extensive set of algorithms some of which are currently not available in commercial software (Harinder, 2018).

The RS2-CHIM system is composed of the following subsystems: (1) An image processing subsystem responsible for producing raw updated shapes for each valid water body. (2) A post-processing subsystem responsible for quality control, simplifications and report generation. (3) A web interface that enables the user to view and consult the results (Harinder, 2018).

5.0 Final Discussions on Space Technology Application for Water Quality

Space-based technologies has various advantages related to area coverage, timeliness, and measurement frequency as mentioned, therefore it can be applied fruitfully to the important field of water quality. More-so, the application of satellite technology and space technology spin-offs in water quality monitoring for the achievement of sustainable development cannot be over-emphasized (Harinder, 2018).

More improvement can be expected even as the new satellites with more precise polarimetric sensors become available along with new application software. Although the currently used ones are not doing too badly. Next step will be to find some means of doing bottom profiles of water-bodies using Remote Sensing (Bouilly, 2014).

Bouilly, (2014) also stated that until today, no one has managed to locate the plastic accumulation zones in water from space, as there are many constraints to be considered. The presumed location of plastic, the navigation constraints, the needs of the other scientific components and satellite trajectories are the mentioned constraints. Some of the problems to overcome as a result of the deceitful pollution which cannot be easily seen because of the

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millimeter length nature, sub-surface floatation and the relatively low concentration. It is hoped that very soon, these constraints will be overcome.

So many people think that the space technology is abstract and inaccessible. This is not true as open source libraries of space data can be gotten online (which may be for free or not) for water quality measurement, although these set of algorithms on water quality are currently not available in commercial software (Harinder, 2018). There will be a need to be trained to interpret remote sensing images, as they are raw data. Satellite images can be processed on powerful personal computers and relatively simple and low-cost software packages. Being trained to be able to interpret remote sensing images will be a very good step for the water professionals and people in need as they could get some free useful images from the internet on specific water quality monitoring. (Oluwafemi and Olubiyi, 2018a).

6.0 Conclusion

Space-based technology indeed needs to be looked into more as a solution to the world's water quality monitoring as it gives us solution on a global scale. This targets the three pillars of sustainability: economic development; environmental protection; and social equity. This is in-line with the Goal 6: Clean water and Sanitation SDG of the United-Nations.

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