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# OVERCOMING THE CHALLENGES IN THE REMOTE SENSING APPLICATION TO INLAND WATER QUALITY MONITORING

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**Abstract-** Water quality monitoring is a crucial issue that is of global concern. The rapidly deteriorating state of lakes across the world makes their monitoring of extreme importance to ensure effective management and sustainability. The traditional monitoring approach is costly, inaccurate and highly limited. The remote sensing (RS) techniques provide unique tools to effectively monitor the surface constituents on spatio-temporal basis. However, daunting challenges are encountered during the retrieval process especially when considering turbid lakes. The present study critically addressed the challenges through careful analysis of the causes. The key challenges were observed to include atmospheric correction failure, inappropriate selection of models as well as data unavailability or inadequacy. This study investigated these challenges and proposed effective measures to overcome them. This provides vital information that would serve as a quick guide to all concerned professionals. It also adds to the effort already in place to ensure effective monitoring, studies and exploitation of turbid lakes water quality parameters. RS techniques can therefore be taken as an independent measurement tool for water management especially turbid lakes across the world.

**Keywords-** atmospheric correction failure, challenges, in-situ data, models, remote sensing, water quality

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## Introduction

Inland surface waters are extremely important for a variety of purposes including drinking, domestic usage, agricultural activities and tourism among several other uses. This shows their benefits cannot be underestimated as it proves to be a major source of livelihood across the globe. Therefore, environmental protection is highly needed for efficient management and sustainability of these natural resources. It is critical to note that the rapid increases in the anthropogenic activities within watersheds in recent times pose serious global concern. These activities, exacerbated by climate change, have led to the rapid deterioration of various surface water bodies with dire effects on aquatic organisms, public health and the environment at large. Therefore, monitoring water quality (WQ) is critical and timely.

Over the years, various regions have employed traditional methods in the monitoring procedure which is costly, time consuming, inaccurate, labor intensive and extremely limited. More importantly, these methods do not give a synoptic view of a water body or different water bodies across the globe. It may require a lot of travelling, sampling and expensive laboratory analysis especially for large water bodies. Thus, a need for improved methods has become necessary and urgent. Remote sensing (RS) techniques present a unique tool that can be used to effectively monitor these parameters [1-3]. Its ability to retrieve water quality parameters, over large areas simultaneously, on spatial and temporal basis makes it highly accessible, critical and necessary [4].

As a result, RS techniques have been successfully employed in several water quality studies [5-14]. Specifically, water color remote sensing from airborne or space-borne sensors can observe the concerned parameters related to chlorophyll, Suspended Sediments (SS) as well as the Colored Dissolved Organic Matter (CDOM) [15,16]. The application of this RS technique in water quality monitoring lies in the fact that the optical properties of water bodies present unique signatures that can be detected using sensors [17-20]. This implies that RS techniques can be utilized successfully to retrieve the water quality parameters of the rapidly deteriorating water bodies such as lakes. Surprisingly, very few studies have been conducted on inland surface water bodies especially lakes [21]. It is quite unfortunate to note that although there are several benefits that may be derived from applying RS techniques, daunting challenges are encountered during the processing of the RS data in retrieving these critical water quality parameters. The challenges may include atmospheric correction failure, selection of inappropriate models as well as lack or inadequate in-situ data.

The present study sought to critically address the challenges that are normally encountered during the processing of RS data for the estimation of water quality parameters. It must be noted that special focus was placed on turbid lakes since the surface constituents

such as suspended solids and bubbles, greatly hinder the successful retrieval of the concerned parameters from the remotely sensed data. Specifically, the three main challenges considered were atmospheric correction failure, inappropriate choice of models and lack or inadequate in-situ data. The challenges were initially explored before the solutions were proposed.

**Challenges of RS Application to Water Quality Monitoring in Turbid Lakes**

According to Chen & Yu [4], two issues are very important for water color remote sensing: atmospheric correction and the quantitative retrieval of water quality parameters. The authors pointed out that more than 90% of the signals measured by an ocean color satellite sensor is due to the confounding influence of the atmosphere. It must be emphasized that the fraction of radiance reflected from water column is very small and therefore accurate radiometric correction is critical. The atmospheric correction procedure is performed to remove the atmospheric and water surface effects. This is done to facilitate the processing of the radiance signals for reliable interpretation. Basically, the purpose of atmospheric correction is to obtain water-leaving radiance that contains useful information about the water constituent. The atmospheric effects on RS of oceans can easily be corrected. However, this correction normally fails when it is applied to inland water bodies. This failure is more pronounced when dealing with turbid lakes [22]. Also, the quantitative retrieval of water quality parameters is highly dependent on the choice of models and the availability of the requisite in-situ data. It must be noted that in order to successfully retrieve quantitative values of water quality parameters from remotely sensed image, in-situ data must be available to validate the retrieval algorithms or models.

Mostly, in-situ data are unavailable or inadequate and this compounds the difficulty during the retrieval process.

**Atmospheric Correction Failure**

One of the greatest challenges that have highly limited the application of RS techniques to WQ monitoring is atmospheric correction failure. This is highly crucial when it comes to turbid lakes. On the basis of the black pixel assumption, the values of water-leaving radiance in the near-infrared (NIR) bands are negligible for clear water. As a result, the atmospheric correction of ocean color data as well as the aerosol radiative properties and water-leaving radiance values at various bands are easily determined [22]. On the contrary, the assumption that the water-leaving radiance is zero at near-infrared bands does not hold for turbid lakes. This is because turbid water constituents (suspended sediments, bubbles, etc) can contribute significant amounts of radiance to the atmospheric correction bands. Consequently, the current standard atmospheric correction algorithms frequently overestimates the radiance from aerosol scattering and aerosol-Rayleigh interaction, and underestimates water-leaving radiance at some visible bands, even yielding negative values at the green and blue spectra. It is also important to note that the atmospheric algorithms that are proposed to overcome these challenges are either difficult to use or the assumptions do not hold. Furthermore, there are lapses in the input parameters that are normally used in the algorithms. All these factors make the atmospheric correction procedure a very challenging task when dealing with turbid lakes. In most cases, atmospheric correction failure is the outcome.

**Inappropriate Selection of Models**

Another critical challenge that is worth mentioning is the inappropriate selection of models that are used to predict the water quality parameters from the remotely sensed data. It must be emphasized that there are several models that have been proposed for the quantitative retrieval of water quality parameters from the remote sensing data. These include theoretical, semi-analytical and empirical models [23]. One important point that is worth mentioning is that although there may exist several models, the retrieval of water constituents in turbid lakes is particularly difficult. This is as a result of the complicated nature of the optical properties of the constituents which include suspended solids. This difficulty is however, further compounded when inappropriate models are selected. The choice of wrong models during the parameterization procedure may lead to overestimation or underestimation of the requisite parameters. The critical aspect is that it may sometimes lead to false positive results. The results may be regarded as right whereas in reality, might not be the case. Also, when inappropriate models are used, it may just complicate the retrieval process resulting in failure of information retrieval from the input data.

**Inadequate In-Situ Data**

Furthermore, the lack or inadequate in-situ data of most turbid lakes also presents a great obstacle in the successful implementation of the RS technique to water quality monitoring. This is because RS data are normally compared with in-situ data to establish correlation that would ensure the reliability of the results obtained from the RS technique. Secondly, there are some parameters needed for the processing of the RS data that must be obtained from in-situ data. The lack or inadequate in-situ data therefore hinders the successful application of RS technique to effective water quality monitoring [23] and thus, unrealistic values may be assumed that could lead to unreliable results. It must be emphasized that the lack or inadequate data on lakes is one of the major issues of global concern. Most lakes across the globe are worst affected. Data on these lakes are highly limited and in most cases, unavailable. The causes of this challenge include the cost of measuring the requisite parameters, ignorance about the need to record such data, lack of efficient measuring apparatus, inadequate skilled personnel, faulty measuring tools as well as lack of commitment to water research, among several others.

The challenges discussed above greatly hamper the successful application of RS techniques to water quality monitoring, study and exploitation. In order to overcome these challenges, the present study has critically outlined measures that can be adopted for successful implementation.

**Proposed Solutions**

**Overcoming the Atmospheric Correction Failure**

One of the leading causes of the atmospheric correction failure during the processing of RS data of turbid lakes is the assumptions that are made when performing the atmospheric correction [24]. The assumption that the water-leaving reflectance (WLR) is zero in the NIR band (mostly used when dealing with clear waters) does not work for turbid waters [25,26]. It is important to note that a number of improvements can be introduced to correct the effect of the NIR contribution on water-leaving radiance. This would ensure successful retrieval of the aerosol scattering and aerosol-Rayleigh interaction terms used in the atmospheric correction procedure

[23,25]. Actually, there are two main assumptions that are used to overcome the failure that occurs when the WLR in the NIR band is neglected [27]. Firstly, the ratio of the reflectance due to multi-scattering aerosols must be assumed to be spatially homogeneous over the study area. Secondly, the ratio of WLR in the bands under consideration must also be assumed to be spatially homogeneous over the study area. In addition, the "nearest neighbor" method given by Hu, et al [23] can be adopted in the estimation. It must be noted that since the atmospheric correction algorithms for clear waters are widely known, more research has focused on these water bodies. Undoubtedly, considering the importance of Lake Ecosystem, coupled with the rapid deterioration of these water bodies, it is prudent that much attention is given to the algorithms that would ensure proper atmospheric correction. This would enhance the successful retrieval of the surface constituents.

**Selection of Models**

The selection of appropriate models is also an important component of the RS data processing for the successful retrieval of the water quality parameters. For instance, Volpe, et al [21] asserted that a more general approach should be based on theoretical models of radiative transfer in turbid waters when processing the RS data. In fact, there are several models that have been proposed for this purpose. As indicated earlier, these include theoretical, semi-analytical and empirical models. Since there may exist several different models for this particular purpose, there is a high tendency of selecting one that might not be appropriate for the case under consideration. As a result, there is the need to be extra careful when choosing the model. Because of the difficulties that are already associated with RS water quality monitoring in turbid lakes, the following factors must be strictly adhered to when selecting a model for the successful retrieval of the parameters. One factor that is worth considering is the expected output parameters. If this is clearly known, then the models that may not yield the expected parameters can be eliminated. This would substantially reduce the probability of making a wrong choice. It also saves time in that, only the applicable models would be considered. It is also prudent to note the input data that may be available during the data processing. This factor has high influence on the selection of the models. For example, in an attempt to retrieve suspended particulate matter (SPM) from the Venice lagoon (Italy), Volpe, et al [21] adopted the theoretically- and physically-based approach using a simple radiative transfer model [28,29] to relate at-satellite radiance measurements and in-situ turbidity observations. It must be emphasized that a model that may not take into account the requisite input data for the successful retrieval of the expected parameters is not worth considering. Notably, some models may also require several input data that may not be necessarily needed for the retrieval of the expected output parameters. The unfortunate aspect is that the requisite data may not even be available. Hence, that model would not be applicable. A deeper understanding of the lake under consideration is also required so that the requisite input data can be carefully chosen. This would help in the selection of the appropriate model for the successful retrieval of the expected parameters.

**Approaches Needed to Overcome the Lack or Inadequate In-Situ Data**

Finally, it is proposed in the present study that the problems associated with data unavailability or inadequacy can be overcome through the following approaches. First of all, there is the need for simultaneous measurement of the in-situ data. This is critical for the validation of the RS data. Also, a problem, as a result of inadequate or unavailable data, usually arises when processing past RS data. This is because, with the processing of past data, simultaneous in-situ data cannot be measured if the data for that time period under consideration is unavailable. This is a very crucial problem that needs urgent attention. It is quite unfortunate to note that in-situ measurements are not usually performed on most lakes. This means that some input parameters that may be required for validation of the RS data as well as retrieval of the output parameters may not be available. This is a matter of serious concern because the RS data was acquired in past years. As a result, the concurrent measurements of the in-situ data for the validation process may be of no use. In order to overcome this challenge, in-situ measurement of other lakes can be adopted. This must be done cautiously. For instance, Olet [30] co-opted the Poyang Lake in China to test the validity of the methodology employed in his study owing to lack of in-situ measurements of Chla and SPM concentrations on the Roxo reservoir, Portugal. The present study recommends that more research works should be conducted on lakes to obtain in-situ data that will aid in the validation of the RS method.

**Conclusion**

In conclusion, the present study reveals that, despite the numerous benefits that can be derived when RS techniques are employed in water quality monitoring, very limited studies have focused on inland waters especially turbid lakes. It was found that the retrieval of surface constituents in turbid lakes using RS techniques is particularly problematic. However, it was observed that the problems can be overcome when appropriate measures are adopted. Hence, on the basis of the daunting challenges that are usually confronted, this study has proposed adequate measures to ensure the successful retrieval of the water quality parameters. The present study highlighted the key challenges to include factors such as atmospheric correction failure, inappropriate selection of models as well as in-situ data unavailability or inadequacy. For each problem, critical analysis was carried out to ascertain the causes as well as its effects on the retrieval process. This study therefore provides vital information that is helpful in several aspects. It would serve as a quick reference to researchers in this field. This study further adds to the efforts already in place to ensure effective water quality monitoring, studies and exploitation. It is therefore evident that the RS techniques can serve as a unique tool for the effective monitoring of the rapidly deteriorating lakes across the globe. This would enhance environmental protection and ultimately, sustainability.

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