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NEOM Regional Baseline & Monitoring Program

**Remote Sensing Standards**

Amec Foster Wheeler Energy and Partners Engineering Company – April 2021

Report for

NEOM

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# Introduction

## Preamble

The following document entitled “Standards and Methods: Remote Sensing” was developed by Wood staff on behalf of NEOM and forms one of our core deliverables for the NEOM Baseline Environmental Survey contract. This version of the document (version 1) was developed in early February 2021 and was written and reviewed by senior members of Wood’s Remote Sensing and GIS/spatial analytics team based in Canada and the UK.

The document summarizes the general standards and methods to apply Remote Sensing (RS) methods to different environmental survey applications. A brief introduction of RS and its advantages over field surveys are provided in Section 2. This provides the context for the remainder of the document (Sections 3-11), which outlines recommended RS standards and methods which can be deployed to deliver future environmental surveys for the NEOM project. These topics surveys are: weather and climate, air quality, physical landforms, terrestrial flora and vegetation, soil quality, marine sediment quality, marine water condition, benthic primary producer habitats, and marine fauna.

It should be noted that most of the RS techniques and models described in this document require the capture of field data. This data is needed to both train and implement RS classification models; and also to assess the accuracy of the final outputs. In this document, the standards for RS are discussed in detail, while those related to field survey are briefly provided. More information about the standards and methods for undertaken focused environmental field surveys can be found in the accompanying standard documents produced by Wood

## Project Background

Located in the northwest of Saudi Arabia on the Red Sea and Gulf of Aqaba coasts, NEOM spreads over an area of 26,500 km2 and encloses areas with a wide variety of activities and receptors. Very little information is currently available to characterize air quality condition in the region making necessary to collect primary data to support permit application for future developments.

As part of the NEOM Regional Baseline & Monitoring Program, NEOM required the development of a standard approach to the performance of remote sensing activities to ensure that surveys for different NEOM developments will be undertaken in a consistent manner and to a level that meets or exceeds international best practice.

This document has been developed to describe in detail how remote sensing is used to support baseline surveys across and range of topics as set out below.

# Definitions and Standards

RS is the science of obtaining information about objects on the earth from sensors which are installed on some platforms, such as Unmanned Aerial Vehicles (UAVs), aircrafts, and satellites. Each remote sensor measures electromagnetic radiation reflected, emitted, or backscattered from the Earth. Through recording and analysing this electromagnetic energy, it is possible to produce valuable information from different objects on the Earth.

RS techniques have been effectively utilized for various onshore and offshore applications. Although RS is usually not as accurate as field surveys, its numerous advantages over the traditional field-based methods makes it appealing for different applications, especially for long-term analysis over large areas. The most important advantages of RS methods are provided below:

* RS methods are very cost effective. There are also many open-source satellites, the use of which can further reduce project costs. This significantly reduces the cost especially for monitoring tasks over large areas.
* RS data can be acquired quickly and in real-time, ensuring site information is up to date.
* RS methods are not labour intensive as there is minimum need for field surveys, which mitigates the risk to personnel in remote locations.
* RS instruments can acquire images from almost everywhere on the earth, which further mitigates any risk associated with sending personnel to remote locations.
* RS images can cover a large area (e.g., the entire Saudi Arabia can be covered by only a couple of images by some satellites). Therefore, it considerably facilitates mapping the entire area in comparison with field surveys or ground stations which provide information from specific locations.
* RS users have access to archived and repetitive consistent observations, which allows for cost-effective and reliable change analysis over a desired period.
* RS products can be conveniently imported into Geographical Information System (GIS) environments and combined with other types of datasets.

Each RS system has some characteristics that should be considered before starting to work on any project. In this document, three characteristics of spatial resolution, spectral resolution, and temporal resolution of RS imagery are briefly discussed. It is highly required to investigate the suitable resolutions, which depend on the objectives of each project, before starting any RS project.

## Spatial resolution

Spatial resolution is simply the pixel size of an image or the size of the smallest object that can be detected in an RS image. Higher spatial resolution means more details that we can see in an image. For example, Figure 1 shows two satellite images with different spatial resolutions. Figure 1 (a) illustrates an image captured by the European Senstinel-2 satellite with the spatial resolution of 10 m. As is clear, we can only see the main land cover classes, such as urban area (white areas), water bodies (black areas), woodland or grassland or farmlands (green areas). On the other hand, Figure 1 (b) shows an image acquired by the Worldview-2 satellite with the spatial resolution of 0.5 m. In this image, we can see more details, such as buildings, single trees, grassland, woodlands, and more. We can also observe the pattern of farmlands and texture of woodlands.

|  |  |
| --- | --- |
|  |  |
| **(a)** | **(b)** |

Figure 1. Spatial resolution difference: (1) Sentinel-2 image with the spatial resolution of 10 meters, (2) Worldview-2 image with the spatial resolution of 0.5 meter.

## Spectral Resolution

RS systems acquire electromagnetic energy at different parts of the electromagnetic spectrum which are called spectral bands (e.g., visible and near infrared bands). Spectral resolution simply refers to the number of spectral bands in a sensor. More spectral bands usually mean more information that we can obtain from an area. As an example, main classes such as water, woodland, and grassland can be easily separated using multi-spectral sensors which have a couple of spectral bands. However, if the objective of a project is differentiating very similar classes, such as different grasslands or various woodlands, more spectral bands are required and, in this case, it is better to use hyperspectral RS systems. As another example, if the objective is the vegetation condition assessment, such as discriminating healthy and stressed vegetation, it is recommended to use hyperspectral sensors.

## Temporal Resolution

Temporal resolution refers to the revisit time of satellites, meaning that how much time a satellite needs to capture the same area on earth. For example, European Sentinel-2 satellite acquires images every 5 days from a specific area. Therefore, the temporal resolution of Sentinel-2 is 5 days. The temporal resolution is important for change analysis in an area. This also explains the importance of the free satellite data, by which we have access to the archived consistent imagery back to 1984.

# Weather and Climate

RS has great advantages for long-term and frequent weather and climate analysis over large areas because weather stations and offshore instruments (e.g., buoys) can collect data only over some specific points. RS satellites can be used to measure different weather parameters over onshore and offshore areas. These parameters are land surface temperature, rainfall, cloud, ocean surface wind, ocean wave height, and ocean surface current[[1]](#footnote-2).

## Field data

Field data collected by weather stations and instruments over land as well as offshore instruments (e.g., buoys) are used to train and validate the RS models. It should be noted that most RS models for weather and climate studies do not require field data. However, we need field data if the level of accuracy of the RS models should be reported.

## RS data

Different satellites need be used for studying various weather and ocean parameters. Table 1 shows various weather and climate parameters along with the most appropriate satellites the images acquired by which can be utilized for their estimation. It is also worth noting that the best practice is combining the datasets acquired by several satellites to measure each parameter to obtain the highest possible accuracies.

Table 1. Satellites with capabilities to measure different weather and ocean parameters**.**

|  |  |  |
| --- | --- | --- |
| **Weather and climate parameter** | **Satellite** | **Source** |
| Land surface temperature | Landsat-8, MODIS | <https://earthexplorer.usgs.gov/>  <https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/products/MOD11A1> |
| Rainfall | TRMM | <https://developers.google.com/earth-engine/datasets/catalog/TRMM_3B42> |
| Cloud | Landsat-8 | <https://earthexplorer.usgs.gov/> |
| Ocean surface wind | MetOP, ScatSat-1, GCOM-W, SSMIS, Sentinel-1 | <http://www.osi-saf.org/?q=content/wind-products>  <https://scihub.copernicus.eu/dhus/#/home> |
| Ocean wave height | Sentinel-1, Sentinel-3 | <https://scihub.copernicus.eu/dhus/#/home>  <https://resources.marine.copernicus.eu/?option=com_csw&product_id=GLOBAL_ANALYSIS_FORECAST_WAV_001_027&view=details> |
| * Ocean surface current | * OSCAR satellites | * <https://resources.marine.copernicus.eu/?option=com_csw&product_id=MULTIOBS_GLO_PHY_NRT_015_003&view=details> * <https://www.esr.org/research/oscar/oscar-surface-currents/> |

## Methodology

For most of the weather and ocean parameters, the available products are directly utilised. The reason is these products usually contain the highest possible accuracies. However, for some of the products, such as ocean wind and ocean wave, several advanced RS models should be developed to combine the datasets acquired by different satellites to obtain higher accuracies. It is worth noting that the satellites used in this project have temporal resolutions of 6 to 16 days, meaning that every 6-16 days, a map can be generated from the entire study area. Therefore, for the monitoring phase, a cloud-based platform can be developed to automatically download, process, and apply RS algorithms, and to produce up-to-date air quality maps. The final results can be also provided in user-friendly websites.

## Accuracy assessment

As discussed, the field data are used for accuracy assessment of the RS products. To this end, various statistical analyses are conducted to compare the results with in-situ data and the level of accuracies are reported.

# Air quality

Although ground stations provide highly accurate air quality data, they cannot cover the entire study area. Moreover, the installation and maintenance of these stations are expensive. Therefore, RS datasets are employed to monitor air quality over the entire study areas with minimum cost[[2]](#footnote-3).

## RS data

Three different types of RS datasets are used for air quality monitoring over the entire study area. Table 2 shows the characteristics of these datasets and their purposes.

The datasets acquired by Sentinel-5P and MODIS satellites are valuable resources for air quality monitoring. These datasets can be used for studying various air quality parameters, such as ozone, methane, nitrogen dioxide, formaldehyde, sulphur dioxide, carbon monoxide, dust, and aerosols. These datasets are free and facilitates air quality monitoring over large areas with minimum amount of budget. Moreover, they provide daily data from any study area. Their main limitation, however, is their low spatial resolution (i.e., 1-7 km).

If higher spatial resolution air quality products are required for some specific regions within the study area, the GHGSat imagery should be purchased. These datasets are specifically generated for air quality monitoring and are very high resolution. A key limitation of this data is that they are relatively expensive and only provide information about methane and carbon dioxide.

Table 2. Satellite datasets for air quality mapping and monitoring.

|  |  |  |
| --- | --- | --- |
| **Satellite** | **Spatial resolution** | **Purpose** |
| Sentinel-5P, MODIS | 1-7 km | Air quality mapping and monitoring over the entire study area with minimum cost, Analysing different air quality parameters with low spatial resolution |
| GHGSat | 50 m | Very high resolution methane and carbon dioxide mapping over specific sites |

## Methodology

For most of the air quality parameters, the available products are directly utilized. The reason is that these products usually contain the highest possible accuracies. However, for some of the products several advanced RS models are developed to combine the datasets acquired by different satellites to obtain higher accuracies. It is worth noting that the satellites used in this project have temporal resolutions of 1 day. Therefore, for the monitoring phase, a cloud-based platform can be developed to automatically download, process, apply RS algorithms, and produce up-to-date air quality maps. The final results can be also provided in user-friendly websites.

## Accuracy assessment

The data from the ground stations are compared with the air quality estimations from the satellite data, and the accuracy will be reported.

# Physical Landforms

A widely utilised RS technique for landform analysis is the Interferometric Synthetic Aperture RADAR (InSAR) analysis. The diversity in radar RS sensors with various characteristics along with recent development in InSAR technology has made this technique a preferred geodetic method for the survey of landforms. This technology provides valuable information about the outcomes of both rapid and slow subsidence or sinkholes on infrastructure in industrial and urban features. In addition, InSAR provides insight into the geological and hydrogeological parameters to characterize the aquifer. The remainder of this section focuses on the development and delivery of landform analysis using InSAR techniques[[3]](#footnote-4).

In writing this section of the standard, we also acknowledge the potential benefits and role of using UAVs to capture detailed terrain data for selected areas of the NEOM development. This potential is currently being investigated and this standard document is likely to revised in the future with additional information concerning these techniques.

## Field data

Field data are only required for accuracy assessment of the InSAR results. However, it is widely believed that the accuracy of the InSAR methods for landform analysis is very high and this method can detect land topographic changes with a few millimetres of accuracy. Therefore, it is recommended to collect field data, but it is not necessary.

Field data should be collected using Real Time Kinematic Differential Global Positioning System (RTK DGPS) methods. The data should be collected at some specific points over different time intervals to assess the land vertical changes over time.

## RS data

Field data are only required for accuracy assessment of the InSAR results. However, it is widely believed that the accuracy of the InSAR methods for landform analysis is very high and this method can detect land topographic changes with a few millimetres of accuracy. Therefore, it is recommended to collect field data, but it is not necessary.

Field data should be collected using Real Time Kinematic Differential Global Positioning System (RTK DGPS) methods. The data should be collected at some specific points over different time intervals to assess the land vertical changes over time.

Table 3. The required satellite datasets for physical landform analysis.

|  |  |  |
| --- | --- | --- |
| **Satellite** | **Spatial resolution (m)** | **Purpose** |
| Sentinel-1 | 10 | Landform monitoring over the entire study area with minimum cost and very high vertical accuracy |
| TerraSAR-X | 1-20 m | Landform monitoring over specific regions with a very high vertical accuracy |

## Methodology

InSAR uses two or more radar images that are captured from the same area but from different locations and/or at different times. There are several methods for landform analysis, but the two most common methods are the Small Baseline Subset (SBAS) and Persistent Scatterer (PS) InSAR time series techniques to map landforms. Various processing steps, including pre-processing, co-registration, creating interferograms, removing the effect of topography, atmosphere, and noise, and phase unwrapping are applied to SAR images to produce the final landform map.

## Accuracy assessment

If the GPS measurement are available over the time the InSAR analysis was conducted, the InSAR analysis is compared with the field data, and the accuracy is reported.

## Recommended processing software

A variety of software can be used for the processing of InSAR data for landform analysis. A particularly comprehensive tool is the commercial Sarproz software product[[4]](#footnote-5) with the commercial ArcGIS GIS software providing additional capabilities for general raster/grid-based analysis and processing.

# Terrestrial Flora and Vegetation

The occurrence and abundance of certain plant species and their ecological features provide information about the environmental conditions that are important for understanding the nature of the ecological site, ecological risks, and feasibility of different restoration alternatives. In this section, the requirements and methods for terrestrial flora and vegetation analyses using RS methods are provided. To this end, the method section has been divided into three subsections of land cover classification, land cover change analysis, and species diversity mapping.

## Field data

Before conducting field surveys, the main land cover types over the study area are identified by performing an unsupervised[[5]](#footnote-6) classification and visual interpretation of Google Earth imagery and ArcGIS base maps. Then, using these analysis, Wood’s environmental and ecological scientists identify the approximate location of homogeneous land cover types over the study area.

Field sites are selected from the sites of homogeneous land covers based on site accessibility. Wood field scientists then survey those selected areas, collecting various field data. Field data include GPS points collected at the locations of each homogeneous land cover class site, photographs, and descriptions. This information is also commonly referred to as “Ground truth” data.

The ground truth samples are then typically imported into a GIS software product (such as ArcGIS or QGIS), and pre-processed to make them ready for RS models. This work may include converting GPS points into polygons indicating the boundary of different objects (see Figure 2). For this purpose, the corresponding notes about the types of each class and photos are also used.

Finally, the ground truth sample locations are randomly divided into two groups of training (50%) and test (50%) data. The training data will be used to develop and train the RS models and the test data will be used for statistical accuracy assessment of the final products.

A close up of a mans face

Description automatically generated

Figure 2. The procedure of converting the field sample points to the GIS polygons. (a) a GPS point collected in the field on a Disturbed area; (b) the generated polygon for this sample of homogeneous land class in the ArcGIS software.

## RS data

Considering different objectives of terrestrial vegetation mapping, three types of satellite datasets can be used. Table 4 shows the characteristics of these datasets and their purposes. These satellite data provide the required information to perform different tasks related to terrestrial flora and vegetation mapping.

Original Sentinel-2 data are free and can be used for obtaining general information about the study area and also used to deliver unsupervised RS classifications to classify the main land cover types. Considering that these data are free, they are also very useful for land cover change analysis over long terms (e.g., several years).

The improved Sentinel-2 data are produced from the original data and have better spatial resolution. Therefore, more details can be obtained from the imagery. The cost for the imagery is considerably lower than any high-resolution satellite imagery and, thus, these images are the best options for accurate land cover classification. Moreover, improved Sentinel-2 images can be efficiently used for species diversity mapping.

If it is required to generate more details from specific areas, the very high-resolution satellite images, such as those acquired by the Worldview-2 satellite, should be purchased. These images are relatively expensive. Therefore, it is suggested to buy them over some small areas where more details are required to be obtained.

Table 4. The required satellite datasets for terrestrial flora and vegetation analysis.

|  |  |  |  |
| --- | --- | --- | --- |
| **Satellite** | **Spatial resolution (m)** | **Purpose** | **Accuracy level** |
| Original Sentinel-2 | 10 | Unsupervised land cover classification; General information about the main land cover types over very large area; land cover change analysis | Medium |
| Improved Sentinel-2 | 2.5 | Supervised classification, delineating more land cover classes with a better accuracy over very large area; Species diversity mapping | High |
| Worldview-2 | 0.5 | Supervised classification, delineating more land cover classes with the highest accuracy over small areas | Very high |

Although satellite images are already partially processed and prepared by the image providers, the geometric and radiometric accuracies, as well as orthorectification and co-registration of the image are investigated to ascertain the image is suitable to be used in the RS models.

## Methodology

### Land cover classification

An unsupervised classification is initially performed to identify different habitat types over the entire study area. The produced map provides a better view about the study area and helps the field staff in finding the locations of different land cover types before conduiting field surveys.

After collecting and processing field data, a more robust supervised classification algorithm is developed based on the training samples (i.e., half of the field samples) to produce a more accurate land cover map with more details. To this end, the most advanced RS and machine learning algorithms, such as the random forest classification algorithm and object-based image analysis are typically developed. Figure 3 demonstrates the flowchart of the proposed method for land cover classification.

Diagram

Description automatically generated

Figure 3. Flowchart of the method for land cover classification.

### Land cover change analysis

Figure 4 shows the flowchart of the method used for land cover change analysis. In this project, the image differencing change detection algorithm is implemented to obtain the changes. The values of 1 and 0 indicate the areas with the highest and lowest changes, respectively.

Diagram

Description automatically generated

Figure 4. Flowchart of the method for land cover change detection.

### Species diversity mapping

Species diversity is a specific RS technique designed to evaluate the variability of land cover types or “species” within a defined geographical area (e.g., 50 m by 50 m plot size). This is assessed using a RS segmentation algorithm, which divides the study area into numerous segments, and then the number of segments into a given area are counted.

In the first step, the satellite imagery is ingested into the eCognition software to conduct a segmentation using the multiresolution algorithm. The result of segmentation is the main input for species diversity mapping. The multi-resolution algorithm applies a bottom-up approach in which pixels are considered object seeds and iteratively grow by being merged with neighbouring objects in a pair-wise manner, depending on the scale, color, and shape parameters defined by the user. The next step is to create 50 m by 50 m plots over the study area. This is automatically conduced in ArcGIS by creating grids over plots. These grids are used as the basis for calculation of species diversity at each plot. Finally, when both the segmentation results and the plots are generated, the two layers are spatially overlayed, and the number of polygons in each plot is automatically calculated using ArcGIS software. These numbers are finally used as an indication of species diversity in each plot.

## Accuracy assessment

Two types of accuracy assessments are conducted for the produced land cover maps. First, the map is analysed and interpreted visually using the high spatial resolution imagery (e.g., those available within ArcGIS and Google Earth) to see if the classes visually correspond to real objects. Second, the statistical accuracy assessment is performed using the test data (i.e., 50% of field samples) to obtain the classification accuracy values through development and analyse of the confusion matrix[[6]](#footnote-7).

## Software

A variety of software can be used for the development of unsupervised and supervised land use classifications. One recommended tool is the commercial eCognition software product with the commercial ArcGIS GIS software providing additional capabilities for general raster/grid-based analysis and processing

# Soil Quality

The spectral information which are obtained from the RS imagery provide the user with information regarding the chemical and physical properties of the objects on the earth. Therefore, statistical relationships can be developed between the spectral bands and soil quality parameters, such as soil texture, soil moisture, and soil temperature. For developing these relationships, a certain amount of field data is required for each of these parameters.

It is worth noting that it is not possible to develop an accurate model for each desired soil quality parameter using RS models. However, for any parameter for which the in-situ data are available, a RS model are developed, and the level of accuracies are reported.

## Field data

For each of the soil parameters required to be mapped, field samples are needed. It should be noted that the entire study area does not need to be surveyed, but surveying representative areas is enough. Later, the field data are divided to two parts, one part for developing the statistical relationship, and the other part for assessing the accuracy of the parameters.

## RS data

Sentinel-2 imagery, which has 12 spectral bands, and the spatial resolution of 10 m, is used for the purpose of this study. The rich spectral information provided by Sentinel-2 imagery is valuable in measuring the properties of the soil. Table 5 shows the characteristics of Sentinel-2 data.

Table 5. The spatial and spectral characteristics of Sentinel-2.

|  |  |  |
| --- | --- | --- |
| **Spectral bands** | **Central wavelength (nm)** | **Spatial resolution (m)** |
| Band 1 – Coastal aerosol | 442.7 | 60 |
| Band 2 – Blue | 492.4 | 10 |
| Band 3 – Green | 559.8 | 10 |
| Band 4 – Red | 664.6 | 10 |
| Band 5 – Vegetation [red edge](https://en.wikipedia.org/wiki/Red_edge) | 704.1 | 20 |
| Band 6 – Vegetation red edge | 740.5 | 20 |
| Band 7 – Vegetation red edge | 782.8 | 20 |
| Band 8 – NIR | 832.8 | 10 |
| Band 8A – Narrow NIR | 864.7 | 20 |
| Band 9 – Water vapour | 945.1 | 60 |
| Band 10 – SWIR – Cirrus | 1373.5 | 60 |
| Band 11 – SWIR | 1613.7 | 20 |
| Band 12 – SWIR | 2202.4 | 20 |

## Methodology

RS techniques along with in-situ data will be applied to produce soil maps over the entire study area. For this purpose, Sentinel-2 images along with field data are pre-processed and statistical relationships are developed between the spectral bands of the satellite imagery, and various soil parameters measured in the field, such as soil moisture, soil temperature, and soil texture. Then, these statistical relationships are used to estimate the soil quality parameters over the entire study area.

## Accuracy assessment

When the soil quality parameters are estimated for the entire study area, the validation field data are used for the accuracy assessment.

# Marine Sediment Quality

Marine sediment has an important role in hydrology, geomorphology, and geological functioning of marine environments. Since various types of contamination affect the spectral signature of sediments, RS can be used to evaluate sediment quality. While the offshore area is large, the collection of in-situ data is restricted to a small number of sites. Moreover, since it is required to monitor sediment quality over time, using in-situ methods is not the most cost-effective approach. Therefore, RS methods are more efficient for marine sediment quality assessment over the entire offshore area.

It is worth noting that it is not possible to develop an accurate model for each desired marine sediment quality parameter using RS models. However, for any parameter for which the in-situ data are available, a RS model are developed, and the level of accuracies are reported.

## Field data

Field samples of marine sediment quality are required for both training the RS algorithm and the accuracy assessment of the product.

## RS data

Open-access Sentinel-2 satellite data (see Table 5) are commonly used to map sediment quality over large offshore areas. This data with the spatial resolution of 10 m is considerably cost efficient and yields a reasonable level of accuracy for marine sediment quality mapping. The temporal resolution of this satellite is 5 days, meaning that sediment can be mapped and monitored every 5 days over the entire offshore area.

Additional detail regarding sediment type/conditions can be derived from the analysis of data captured by an airborne hyperspectral survey. This approach captures hundreds of spectral bands but is a more expensive approach, especially for large geographical areas.

## Methodology

RS techniques along with in-situ data can also be used applied to produce marine sediment quality maps over large geographical areas. For this purpose, Sentinel-2 data along with field data are pre-processed and statistical relationships are developed between the spectral bands of the satellite imagery, and various sediment parameters measured in the field. These statistical relationships are used to estimate the marine sediment quality parameters over the entire study area.

## Accuracy assessment

When the sediment quality is mapped using RS data, it is compared with the field data, and the accuracy is reported using the development of a confusion matrix.

# Marine Water Quality

Marine water is extremely important for the marine habitat, several human activities, and human life. Marine water quality is assessed through estimating different parameters, such as turbidity, sea colour, chlorophyll content, sea surface temperature and salinity using RS data.

Since the offshore area for the NEOM study is large (e.g., 150Km2), it is not possible to analyse water condition over the entire water bodies by collecting in-situ data. Moreover, since it is required to monitor water condition over time, using in-situ observations is not the most cost-effective approach. Therefore, RS can be used to estimate each of these parameters separately and update them in certain time intervals.

It is worth noting that it is not possible to develop an accurate model for every single water condition parameter. However, for any parameter for which the in-situ data are available, an RS model is developed, and the level of accuracies is reported.

## Field data

Field samples of marine water condition are required for both training the RS algorithm and the accuracy assessment of the product.

## RS data

Sentinel-2 imagery (see Table 5), which has 12 spectral bands, and spatial resolution of 10 m is used for the purpose of this study. The rich spectral information provided by Sentinel-2 imagery is valuable in evaluating the quality of water.

## Methodology

Sentinel-2 images will be applied to develop several statistical models to assess water condition through prediction of the water quality parameters.

## Accuracy assessment

When the water quality parameters are mapped using the statistical RS models, the maps are compared with the field data, and the accuracy is reported.

# Benthic primary Producer Habitats

RS imagery has been successfully used to map benthic habitats, including seaweed, seagrass, saltmarshes and corals. However, optical images are only applicable to the shallow waters (e.g., water depth less than 4 meters), and as the water gets deeper, the accuracy of the RS model for benthic mapping decreases.

## Field data

For each of the classes which are required to be mapped, field data are required. Then, the data is divided to two parts, one of which is used for training the RS model, and the other part is used for validation of the results.

## RS data

For benthic habitat mapping, very high-resolution imagery, such as those acquired by Worlview-2 and Worldview-3 or airborne hyperspectral images are required. Table 6 shows the characteristics of these satellites.

Table 6. The characteristics of Worldview-2 and Worldview-3 satellites images.

|  |  |  |  |
| --- | --- | --- | --- |
| **Spectral bands** | **Spatial resolution (m)** | **Spectral bands** | **Spatial resolution (m)** |
| Panchromatic | 0.5 | Panchromatic | 0.3 |
| Coastal | 2.0 | Coastal | 1.2 |
| Blue | 2.0 | Blue | 1.2 |
| Green | 2.0 | Green | 1.2 |
| Yellow | 2.0 | Yellow | 1.2 |
| Red | 2.0 | Red | 1.2 |
| Red Edge | 2.0 | Red Edge | 1.2 |
| Near Infrared 1 | 2.0 | Near Infrared 1 | 1.2 |
| Near Infrared 2 | 2.0 | Near Infrared 2 | 1.2 |
|  |  | Shortwave Infrared 1 | 4.0 |
|  |  | Shortwave Infrared 2 | 4.0 |
|  |  | Shortwave Infrared 3 | 4.0 |
|  |  | Shortwave Infrared 4 | 4.0 |
|  |  | Shortwave Infrared 5 | 4.0 |
|  |  | Shortwave Infrared 6 | 4.0 |
|  |  | Shortwave Infrared 7 | 4.0 |
|  |  | Shortwave Infrared 8 | 4.0 |

## Methodology

Initially, the raw data obtained from the satellite sensors will be adjusted to compensate for known sensor characteristics (radiometric correction), distortions caused by atmosphere (atmospheric correction), and rectified to a projection (geometric correction). Then, the supervised classification algorithm is developed based on the training samples (i.e., half of the field samples) to produce a benthic habitat map. To this end, the most advanced RS and machine learning algorithms, such as the random forest classification algorithm and object-based image analysis would be used.

## Accuracy assessment

Two types of accuracy assessments are conducted for the benthic habitat maps. First, the map is analysed and interpreted visually using the high spatial resolution imagery (e.g., those available within ArcGIS and Google Earth) to see if the classes visually correspond to real objects. Second, the statistical accuracy assessment is performed using the test data (i.e., 50% of field samples) to obtain the classification accuracy values through development and analysis of a confusion matrix.

# Marine Fauna

The visual interpretation of very high-resolution satellite images is applied to detection marine fauna, such as turtle tracking.

## Field data

Field data are collected from the location of turtle nesting. These data are used for the accuracy assessment of the RS model.

## RS data

In this project, a high-resolution Worldview-3 satellite image with the spatial resolution of 30cm (see Table 6) would need to be used to detect turtle nesting near coastlines.

## Methodology

It is expected that a manual visual interpretation of Worldview-3 images would need to be undertaken to detect turtle nesting areas. This exercise would need to be focused on specific areas where turtle nesting is known and/or expected.

## Accuracy assessment

The collected field data will be used to validate the visual interpretation of the satellite images.



1. Refer to <https://www.researchgate.net/project/Met-Ocean-Applications-of-Remote-Sensing> for more information about the remote sensing applications for weather and ocean studies. [↑](#footnote-ref-2)
2. Refer to <https://www.sciencedirect.com/science/article/abs/pii/S1352231021000273> for more information about the remote sensing applications for air quality monitoring. [↑](#footnote-ref-3)
3. Refer to <https://www.researchgate.net/project/InSAR-for-Monitoring-and-Modelling-Different-Geo-Hazard-Events-and-Tectonics> for more information about the InSAR methods for landform analysis. [↑](#footnote-ref-4)
4. [www.sarprox.com](http://www.sarprox.com) [↑](#footnote-ref-5)
5. Unsupervised classification is a form of pixel-based classification and is essentially computer automated classification. The user specifies the number of classes and the spectral classes are created solely based on the numerical information in the data (i.e. the pixel values for each of the bands or indices). [↑](#footnote-ref-6)
6. A confusion matrix (or error matrix) is a quantitative method of characterising image classification accuracy. It is a table that shows correspondence between the classification result and ground truth data. [↑](#footnote-ref-7)