Water Quality Monitoring

From Satellite Imagery

A Case Study in Hong Kong

Presented by:

GRM-PC-517

13 Jul 2024

CSDI Awards 2024 (Category 4)

Link to deliverable (ArcGIS Dashboards):
https://www.arcgis.com/apps/dashboards/3b1a7e3a7ea640a1a2b2338cd774520a

Contact us: khoyinivan@link.cuhk.edu.hk

Total land area of Hong Kong: 1114.6 km²

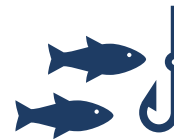**Total sea area of Hong Kong: 1640.4 km²**

(Lands Department, Jan 2024)

Navigation

Recreation

Marine life

Seafood

Water supply
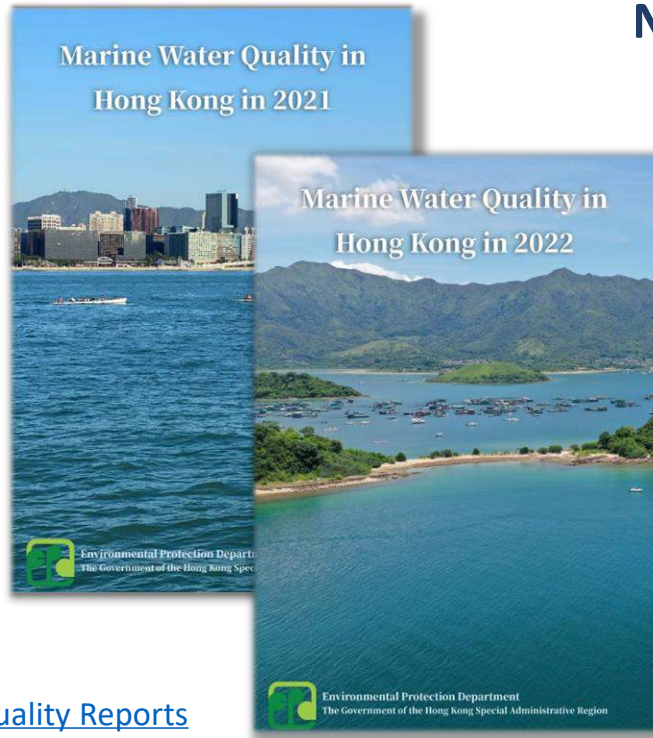
Conventional monitoring methods

Environmental Protection Department (EPD)

- Regular water quality monitoring programme since 1986
- Monthly water sample collection at 94 locations
- Release data as annual reports

New geospatial approach

Spatial coverage

Temporal frequency

Cost efficiency

Source: Environment and Ecology Bureau

Source: Annual Marine Water Quality Reports
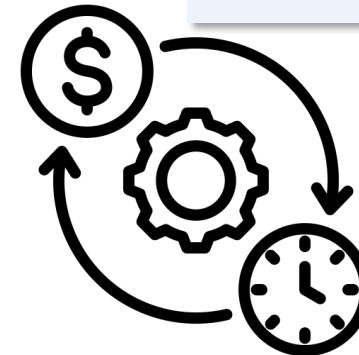
Earth observation satellites
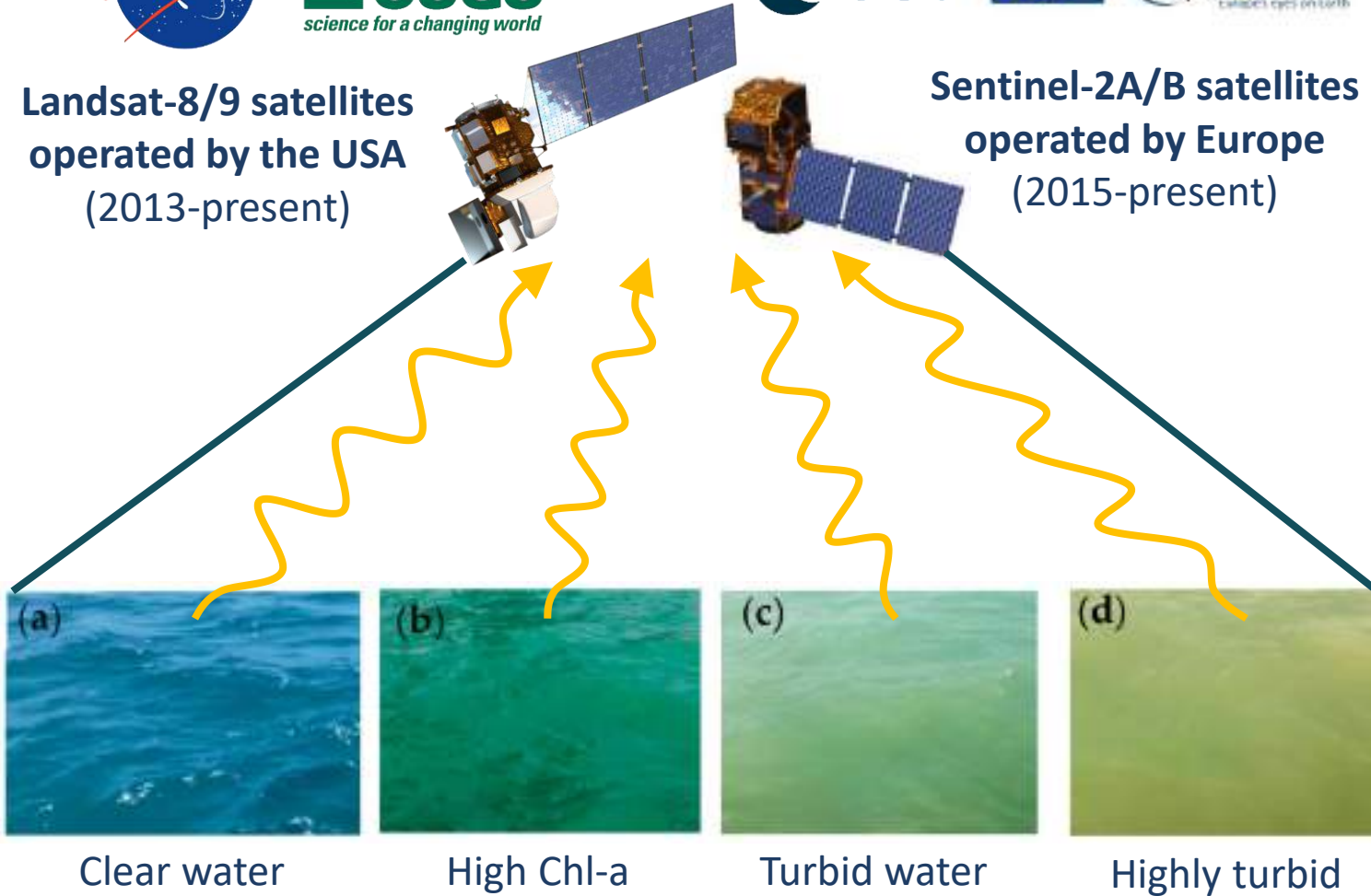
Landsat-8/9 satellites operated by the USA
(2013-present)

Sentinel-2A/B satellites operated by Europe
(2015-present)

- All adopt free and open data policy
- Combined revisit time of 1-3 days
- Collect spectral bands beyond visible lights

Example: Sentinel-2B image on 25/12/2023

(a) Clear water

(b) High Chl-a

(c) Turbid water

(d) Highly turbid

Source: Hafeez et al. (2019)

Water quality data from CSDI Portal

Station name (x-y coordinates)	Measurement date
Values of different water quality parameters	

Two parameters selected in this study

- **Chlorophyll-a**: measurement of photosynthetic pigment, algal production and red tide

- **Suspended Solids**: related to sediment transport, nutrient cycle and water clarity

	A	B	C	D	E	F	G
1	Water Control Zone	Station	Dates	5-day Biochemical Oxygen Demand (mg/L)	Ammonia Nitrogen (mg/L)	Chlorophyll-a (µg/L)	Dissolved Oxygen (%saturation)
2	Deep Bay	DM1	22/1/2022	0.4	0.48	2.2	113
3	Deep Bay	DM1	18/2/2022	1.2	0.49	2.1	76
4	Deep Bay	DM1	9/4/2022	0.9	0.24	4.1	88
5	Deep Bay	DM1	20/5/2022	<0.1	0.63	2.4	83
6	Deep Bay	DM1	13/6/2022	3.1	1.2	45	63
7	Deep Bay	DM1	15/7/2022	3.6	0.088	14	123
8	Deep Bay	DM1	12/8/2022	1.2	1.2	3.5	88
9	Deep Bay	DM1	14/9/2022	1.7	0.28	9.7	86
10	Deep Bay	DM1	13/10/2022	0.9	0.33	6.4	87
11	Deep Bay	DM1	9/11/2022	6	0.56	4.3	65
12	Deep Bay	DM1	8/12/2022	0.8	0.42	2.7	65
13	Deep Bay	DM2	22/1/2022	0.4	0.28	2.2	67
14	Deep Bay	DM2	18/2/2022	1.1	0.2	2.6	81
15	Deep Bay	DM2	9/4/2022	0.8	0.12	9.2	86

GeoAI model

Artificial neural network *(tensorflow.keras.Sequential)*
- Predict water quality from satellite image variables

In situ data
Satellite imagery

Year   2013   2022   2024

Image variables

Water quality (Chlorophyll-a/ Suspended solids)

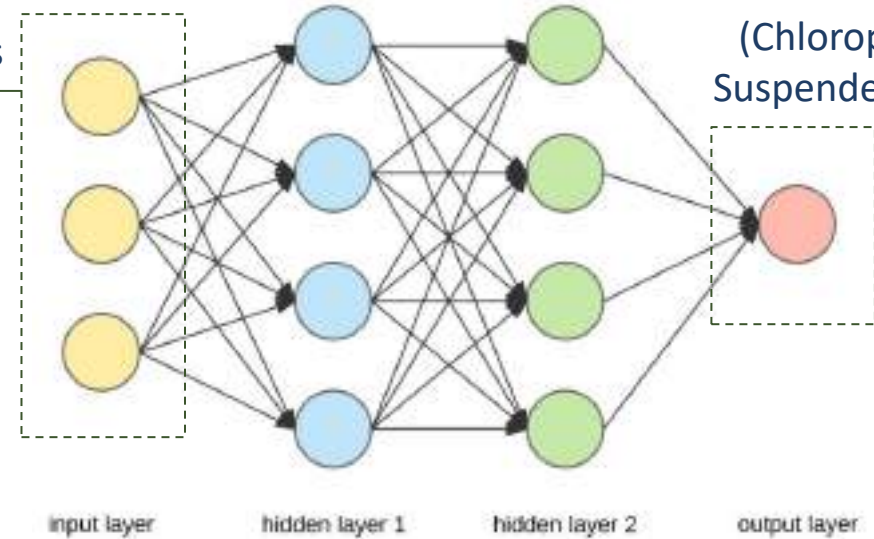input layer   hidden layer 1   hidden layer 2   output layer

① **Training:** Develop model based on matched data on the same date

② **Testing:** Evaluate model accuracy using cross-validation

③ **Predict:** Apply model to all images to produce distribution maps

Model accuracies based on a 10-fold cross validation

	R	RMSE	MAE
Chlorophyll-a	0.606	3.95	1.98
Suspended Solids	0.526	6.46	3.04

Details of the methods are published in a journal article written by the author: ***Frontiers in Marine Science, 2022***

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ORIGINAL RESEARCH article
Front. Mar. Sci., 10 May 2022
Sec. Ocean Observation
Volume 9 - 2022 | https://doi.org/10.3389/fmars.2022.871470

Automatic Mapping and Monitoring of Marine Water Quality Parameters in Hong Kong Using Sentinel-2 Image Time-Series and Google Earth Engine Cloud Computing

Ivan H. Y. Kwong[1,2*]   Frankie K. K. Wong[1]   Tung Fung[1,2]

[1] Department of Geography and Resource Management, The Chinese University of Hong Kong, Hong Kong, Hong Kong SAR, China
[2] Institute of Future Cities, The Chinese University of Hong Kong, Hong Kong, Hong Kong SAR, China
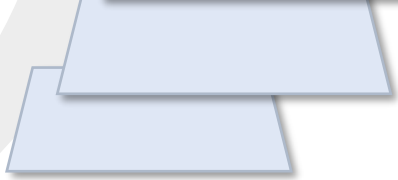
Example of modelling results

Imagery on previous dates

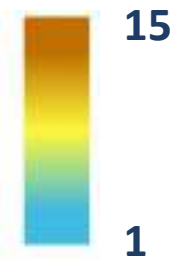Sentinel-2B image on 25/12/2023

Chlorophyll-a
(µg/L)

5

1

Suspended solids
(mg/L)

15

1

Imagery on following dates
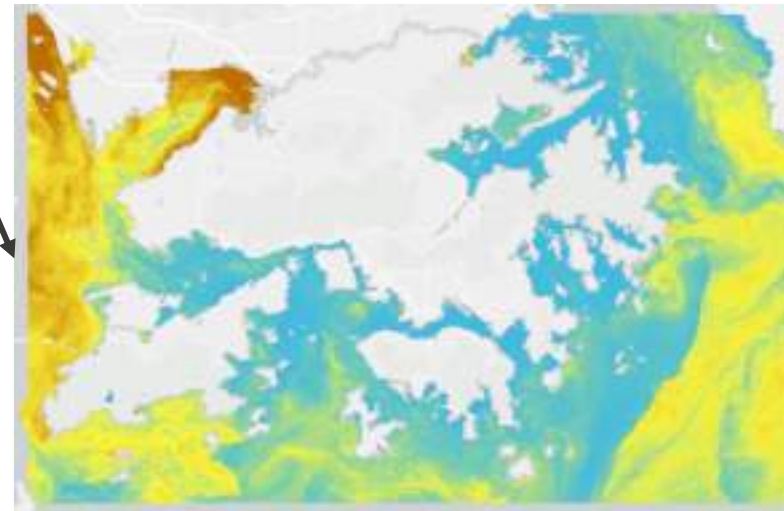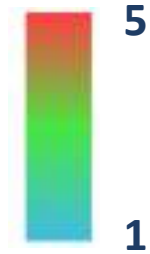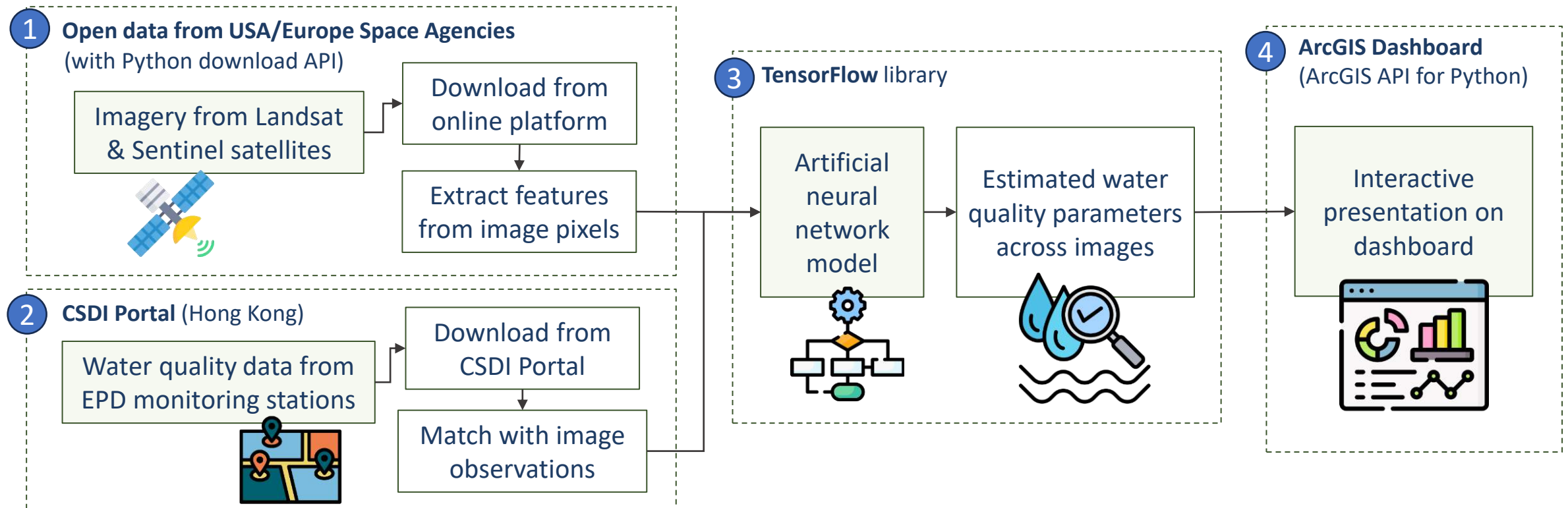
Summary of proposed method

- Develop a geospatial framework to automatically retrieve different water quality parameters on a territory-wide scale for marine waters in Hong Kong
- Integrate **(1) satellite imagery**, **(2) field-measured data** from CSDI Portal & **(3)** open-source **GeoAI models**
- Present the spatial & temporal patterns of water quality using **(4)** a map-centric interactive dashboard

(1) Open data from USA/Europe Space Agencies
(with Python download API)

Imagery from Landsat & Sentinel satellites

Download from online platform

Extract features from image pixels

(2) CSDI Portal (Hong Kong)

Water quality data from EPD monitoring stations

Download from CSDI Portal

Match with image observations

(3) TensorFlow library

Artificial neural network model

Estimated water quality parameters across images

(4) ArcGIS Dashboard
(ArcGIS API for Python)

Interactive presentation on dashboard

An End-to-End Automatic Pipeline developed in Python

Deliverable – Interactive GIS Dashboard

1 Description of the dashboard

2 Interactive selection for temporal & spatial filters

3 Gauges & indicators on the latest estimated water quality levels

4 Time-series charts with scrollbars to select temporal ranges

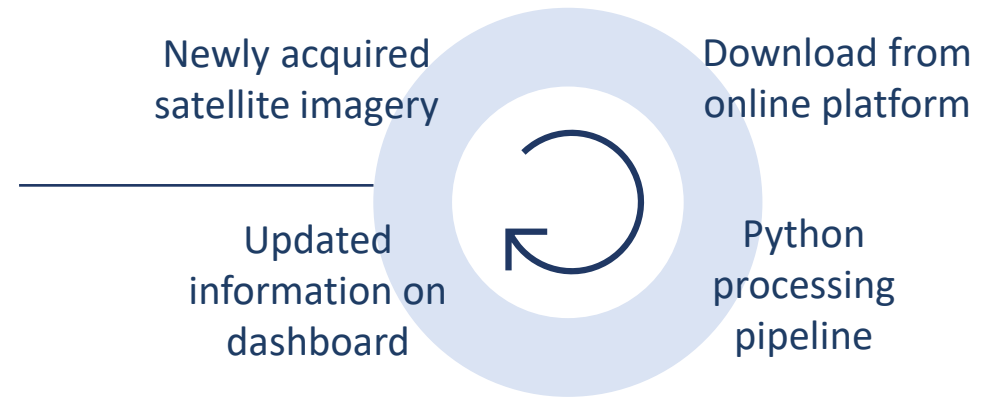**5** Spatial distribution map of the latest situation

6 Interactive selection for spatial subset

Dashboard Link: https://www.arcgis.com/apps/dashboards/3b1a7e3a7ea640a1a2b2338cd774520a
(Snapshot on 25 March 2024)

Potentials of the project

- Deliver timely predictions based on continuously updated satellite imagery and automatic workflow

- Develop as an early-warning system to detect water quality-related events and inform actions

- Further increase monitoring performance by combining commercial data sources from satellites to drones

Newly acquired satellite imagery

Download from online platform

Updated information on dashboard

Python processing pipeline

To government departments:

- Complement conventional methods to enhance efficiency
- Integrate with other emerging smart technologies to move towards a smart environment

To public users:

- Provide an intuitive platform to navigate water quality distributions and trends
- Raise awareness of environmental changes with human activities

環境保護署使用「無人機」、「遙距機械人」及「無人潛水艇」調查水污染問題

推動政府應用創新及科技　#環境保護署

在打擊非法排放污水至河流方面，環境保護署（環保署）的執法人員所面對的挑戰，是要在非

2023 年 2 月 27 日
討論文件

立法會環境事務委員會

應用先進智慧科技進行水質監測和模擬及
改善香港的海洋環境

目的

本文件旨在匯報環境保護署（環保署）在水質監測、水文和水質模擬所應用的先進智慧科技，及改善香港海洋環境方面的最新情況。

Source:

Innovation, Technology and Industry Bureau

Legislative Council Paper No. CB(1)131/2023(05)
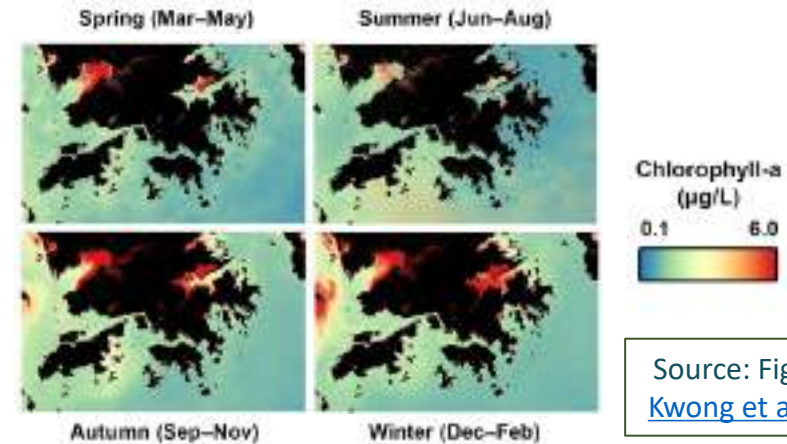
Future development

空間數據・開拓未來
Present Spatial Data, Map our Future

Spring (Mar–May) Summer (Jun–Aug)
Autumn (Sep–Nov) Winter (Dec–Feb)
Chlorophyll-a (µg/L)
0.1 6.0

Source: Figure 5 in Kwong et al. (2022)

- Although this project cannot directly forecast our future

- Historical and current data, seasonal patterns & annual trends serve as a foundation for predicting future events

- Recent example: Beach Water Quality Forecast System by EPD in 2023, considering relevant environmental and hydrometeorological parameters to provide daily forecasts and early warnings

- Technological advancement in GeoAI & deep learning algorithms, together with the increasing volume of satellite and *in situ* data for model calibration, can potentially enhance the prediction accuracy in future

"Learn the Past, Watch the Present, and Create the Future."

Source: RTHK News (15/08/2023)

References

Key reference:

- Kwong, I. H. Y., Wong, F. K. K., & Fung, T. (2022). Automatic mapping and monitoring of marine water quality parameters in Hong Kong using Sentinel-2 image time-series and Google Earth Engine cloud computing. *Frontiers in Marine Science, 9*, 871470. https://doi.org/10.3389/fmars.2022.871470

Government webpages and documents:

- Environmental Protection Department. (2023). *Marine - Annual Marine Water Quality Reports*. https://www.epd.gov.hk/epd/english/environmentinhk/water/hkwqrc/waterquality/marine-2.html

- Innovation, Technology and Industry Bureau. (2024). *The Environmental Protection Department uses drone, robot and submarine to investigate water pollution issues*. https://www.effo.gov.hk/en/our-work/success-stories/environmental-protection-department-uses-drone-robot-and-submarine-to-investigate-water-pollution-issues

- Legislative Council. (2023). *Application of Advanced Smart Technologies in Water Quality Monitoring and Modelling, and the Improvements of the Marine Environment of Hong Kong - LC Paper No. CB(1)131/2023(05)*. https://www.legco.gov.hk/yr2023/english/panels/ea/papers/ea20230227cb1-131-5-e.pdf

Other related research studies in Hong Kong:

- Hafeez, S., Wong, M. S., Ho, H. C., Nazeer, M., Nichol, J., Abbas, S., ... & Pun, L. (2019). Comparison of machine learning algorithms for retrieval of water quality indicators in case-II waters: A case study of Hong Kong. *Remote Sensing, 11*(6), 617. https://doi.org/10.3390/rs11060617

- Nazeer, M., & Nichol, J. E. (2015). Combining Landsat TM/ETM+ and HJ-1 A/B CCD sensors for monitoring coastal water quality in Hong Kong. *IEEE Geoscience and Remote Sensing Letters, 12*(9), 1898-1902. https://doi.org/10.1109/LGRS.2015.2436899

Scientific studies and reviews of the technology:

- Ritchie, J. C., Zimba, P. V., & Everitt, J. H. (2003). Remote sensing techniques to assess water quality. *Photogrammetric Engineering & Remote Sensing, 69*(6), 695-704. https://doi.org/10.14358/PERS.69.6.695

- Wang, X., & Yang, W. (2019). Water quality monitoring and evaluation using remote sensing techniques in China: A systematic review. *Ecosystem Health and Sustainability, 5*(1), 47-56. https://doi.org/10.1080/20964129.2019.1571443

Supplementary materials:

- Kwong, I. H. Y. (2022). Marine Water Quality in Hong Kong - Time Series Estimated from Satellite Images (2015-2021) - GitHub repository. https://github.com/ivanhykwong/Marine-Water-Quality-Time-Series-HK

Acknowledgements

Satellite imagery data (slides 2, 4 and 7):

- Landsat imagery from the U.S. Geological Survey (https://www.usgs.gov/landsat-missions/landsat-data-access)
- Sentinel-2 imagery from Copernicus Sentinel mission of the European Union (https://dataspace.copernicus.eu/)

Figures used in this presentation:

Slide 1
- Artist concept of Landsat 8 (https://www.usgs.gov/media/images/artist-concept-landsat-8)
- Victoria Harbor in Hong Kong (https://www.pexels.com/photo/victoria-harbor-in-hong-kong-15748373/)

Slide 3
- 水質潔淨 樂在維港 (https://www.eeb.gov.hk/en/see_blog/blog20231125.html)
- Annual Marine Water Quality Reports (https://www.epd.gov.hk/epd/english/environmentinhk/water/hkwqrc/waterquality/marine-2.html)
- Efficiency icons created by Uniconlabs – Flaticon (https://www.flaticon.com/free-icons/efficiency)

Slide 4
- Water color in different parts of Hong Kong (https://www.mdpi.com/2072-4292/11/6/617)
- Landsat 8 (https://landsat.gsfc.nasa.gov/article/landsat-data-continuity-mission/)
- Model of Sentinel 2 (https://commons.wikimedia.org/w/index.php?curid=41020894)

Slide 5
- Historical Marine Water Quality Data (https://portal.csdi.gov.hk/geoportal/?datasetId=epd_rcd_1631502576516_76070)

Slide 6
- Neural Network Illustration (https://towardsdatascience.com/video-analysis-with-tensor-decomposition-in-python-3a1fe088831c)

Slide 8
- Satellite icons created by Freepik - Flaticon (https://www.flaticon.com/free-icons/satellite)
- Water quality icons created by Iconjam - Flaticon (https://www.flaticon.com/free-icons/water-quality)
- Operating model icons created by Freepik - Flaticon (https://www.flaticon.com/free-icons/operating-model)
- Results icons created by Freepik - Flaticon (https://www.flaticon.com/free-icons/results)

Slide 10
- The Environmental Protection Department uses drone, robot and submarine to investigate water pollution issues (https://www.effo.gov.hk/tc/our-work/success-stories/the-environmental-protection-department-uses-drone-robot-and-submarine-to-investigate-water-pollution-issues/)
- Legislative Council Paper No. CB(1)131/2023(05) (https://www.legco.gov.hk/yr2023/english/panels/ea/papers/ea20230227cb1-131-5-e.pdf)
- Business and finance icons created by BomSymbols – Flaticon (https://www.flaticon.com/free-icons/business-and-finance)
- Government icons created by Freepik - Flaticon (https://www.flaticon.com/free-icons/government)
- Public service icons created by Job Moon - Flaticon (https://www.flaticon.com/free-icons/public-service)

Slide 11
- Spatial distribution maps of chlorophyll-a concentration (https://www.frontiersin.org/articles/10.3389/fmars.2022.871470/full)
- 環保署推泳灘水質預報系統　每早更新開放泳灘水質預測 (https://news.rthk.hk/rthk/ch/component/k2/1713567-20230815.htm)