Geography Internal Assessment

How does water quality in the Silver Mine River change with distance downstream?

A river field work study investigating downstream changes in river quality on the Silver Mine River

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Contents

List of Abbreviations

SMR	Silver Mine River
WQS	Water Quality Score
SRCC	Spearman's Rank Correlation Coefficient
PMCC	Product-Moment Correlation Coefficient

Introduction

This study aims to answer the **research question**:
How does water quality in the Silver Mine River (SMR) change with distance downstream?

<u>Geography of Area of Study</u>

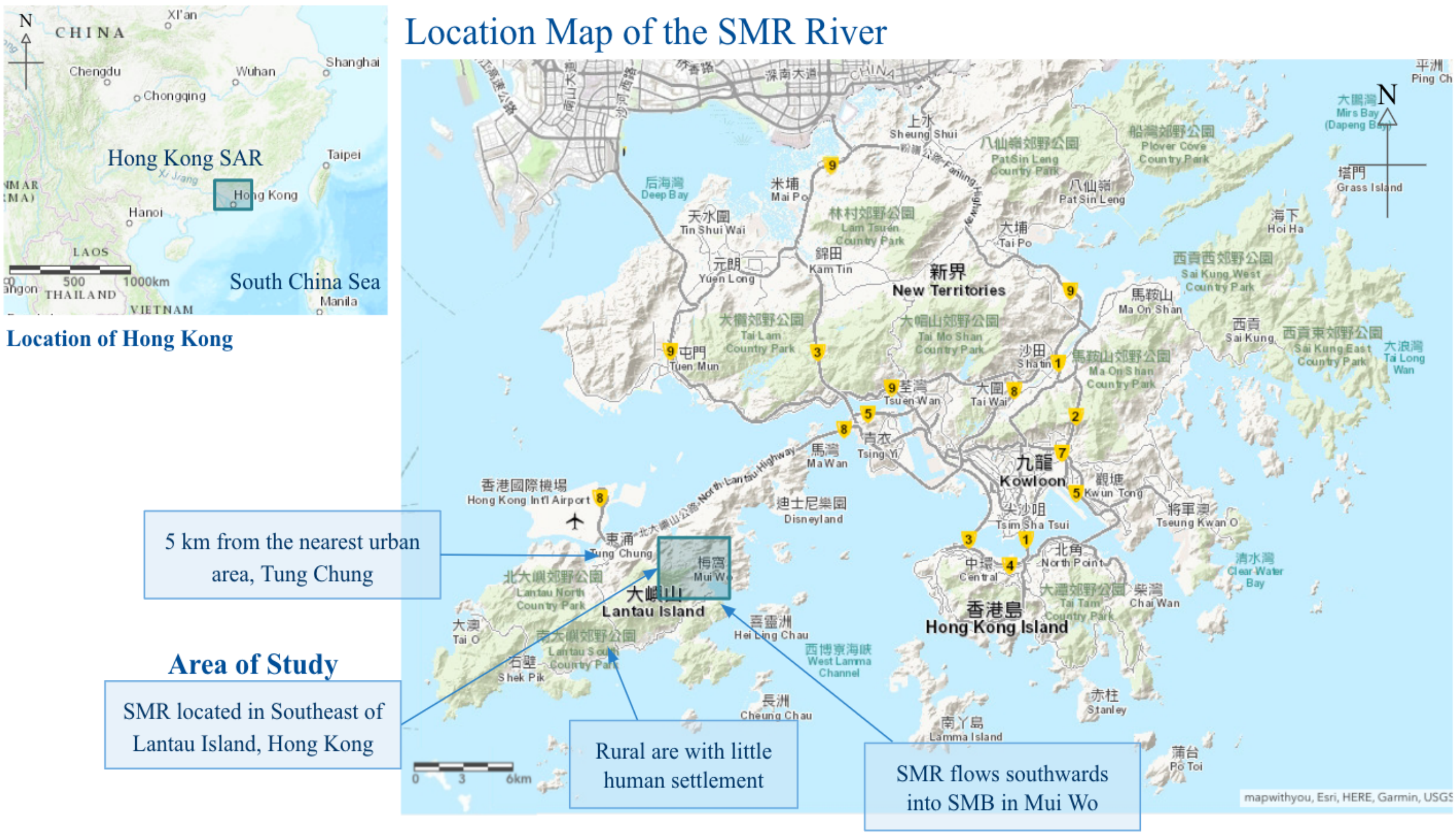

Figure 1.1 Location Map of the SMR

The SMR is located Southeast of Lantau Island, Hong Kong. It flows through Mui Wo, a rural town with a population of 6000 located on the Eastern coast of Lantau Island, Hong Kong[1].

Relation to Syllabus

This study relates to Option A Freshwater, specifically Section 3 (Water Quality) and Section 4 (Water Management)

Primary Research Hypothesis

H_1 - **Primary Research Hypothesis** - Water quality in the SMR will deteriorate with increasing distance downstream.

H_0 - **Null Hypothesis** - Water quality in the SMR is independent of distance downstream.

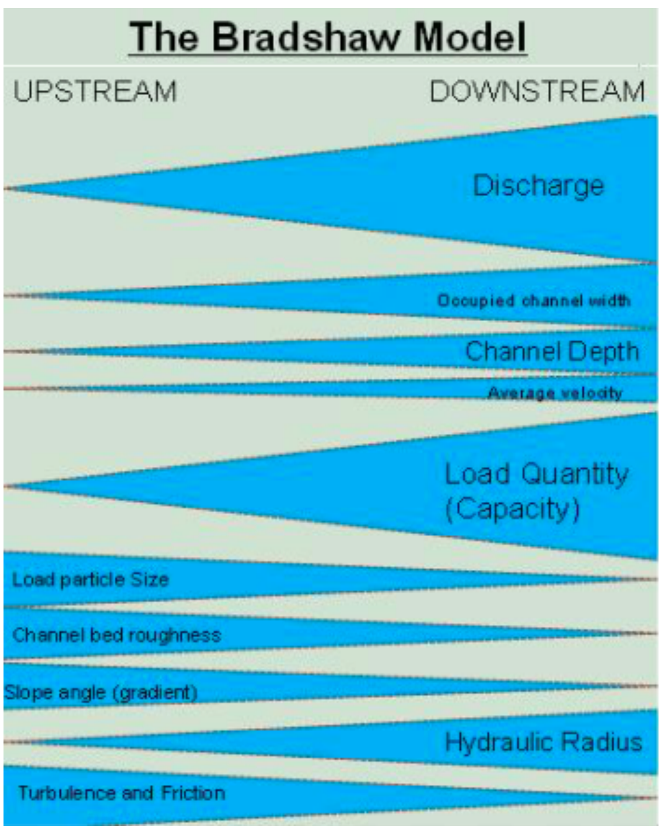

Figure 1.2 The Bradshaw Model states that in theory, load quantity and capacity is expected to increase with distance downstream, allowing for more pollution to accumulate. Moreover, increasing distance downstream would expose the SMR to more point and nonpoint sources of human pollution. Thus, my prediction is that pollution will accumulate and build up from river source to mouth, resulting in deteriorating water quality.

Figure 1.2 The Bradshaw Model[2]

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[1] "Fact Sheet for Tertiary Planning Units 961 - 2011 Hong Kong ...." https://www.census2011.gov.hk/en/district-profiles/tpu/tpu961.html. Accessed: 5 Jan. 2021.

[2] "Applied Geographical skills 2010 - Cool Geography." http://www.coolgeography.co.uk/A-level/AQA/Year%2013/Fieldwork%20investigation/Fieldwork_Investigation_2012.htm. Accessed: 22 June. 2020.

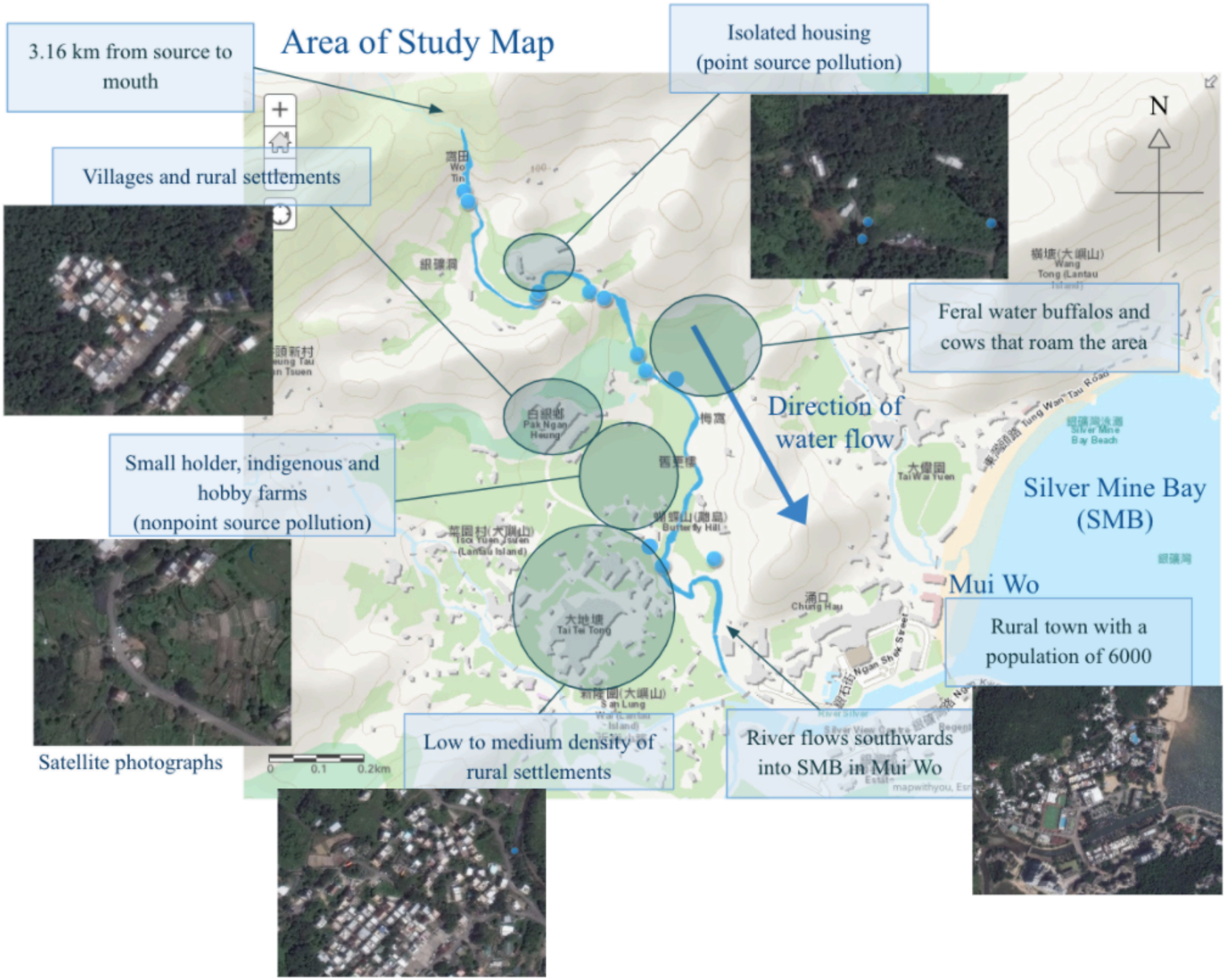

Figure 1.3 Area of Study Map, showing point and nonpoint sources of pollution

Existing governmental research into SMR suggests that livestock farms and unsewered villages are major sources of pollution[3], indicating poor water quality. However secondary sources also suggested that tight governmental regulations, including the Livestock Waste Control Scheme in Mui Wo[4] might have improved river water quality. In terms of geographical factors, secondary sources have stated that water quality in SMR is generally poorer in wet seasons[5].

Secondary Research Hypothesis

H_1 - **Secondary Research Hypothesis -** As dissolved oxygen levels increase, species WQS increases

H_0 - **Null Hypothesis** - There will be no significant relationship between dissolved oxygen levels and species WQS in the SMR

Additionally, I hypothesized that there will be a relationship between dissolved oxygen levels and species Water Quality Score (WQS). Dissolved oxygen levels are expected to decrease downstream due to reduced riparian shading, which in turn rises the temperature of the river leading to decreased oxygen solubility[6]. Moreover, biological oxygen demand is expected to increase downstream, reducing dissolved oxygen levels. Furthermore, species WQS is expected to decrease downstream due to an accumulation of pollution and decreased habitat availability for macroinvertebrates. All these reasons suggest that dissolved oxygen levels might be correlated to species WQS.

Factors that might influence water quality include geographical factors such as river length, rainfall, and time of the year, and human influences such as surrounding agricultural activity.

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[3] "River Water Quality in Hong Kong - EPD." https://www.epd.gov.hk/epd/misc/river_quality/1986-2005/eng/6_lantau_content.htm. Accessed: 22 June. 2020.
[4] "Success Stories | Environmental Protection Department - Epd." 1 Apr. 2020, https://www.epd.gov.hk/epd/english/environmentinhk/water/beach_quality/story.html. Accessed: 22 June. 2020.
[5] "Beach Pollution Source - HKU." http://www.waterman.hku.hk/beach/member/beachpollsnew.aspx?code=SIL. Accessed: 22 June. 2020.
[6] "Dissolved Oxygen - Environmental Measurement Systems." https://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/. Accessed: 6 Feb. 2021.

Methodology

Line systematic sampling will be used to enable comparison between locations of regular intervals, which will allow us to measure downstream changes in water quality. However, due to safety and legal reasons with site access, locations are not equidistant. The data will be collected during a fieldwork excursion to the SMR on Friday, 9th October 2020.

Sampling Location Map

Figure 2.1 Sampling Location Map

Primary Data Collection Methods

Water Quality

Water quality was measured by looking for indicator species, chemical data, riparian index, and levels of dissolved oxygen. This is a **Weighted Composite Index** based on multiple indices.

Measuring Species WQS

Certain invertebrates are associated with high water quality. As invertebrates are bound to their environment, by looking for indicator species, this would indicate water quality from a few days ago. No creatures were harmed in the process of data collection.

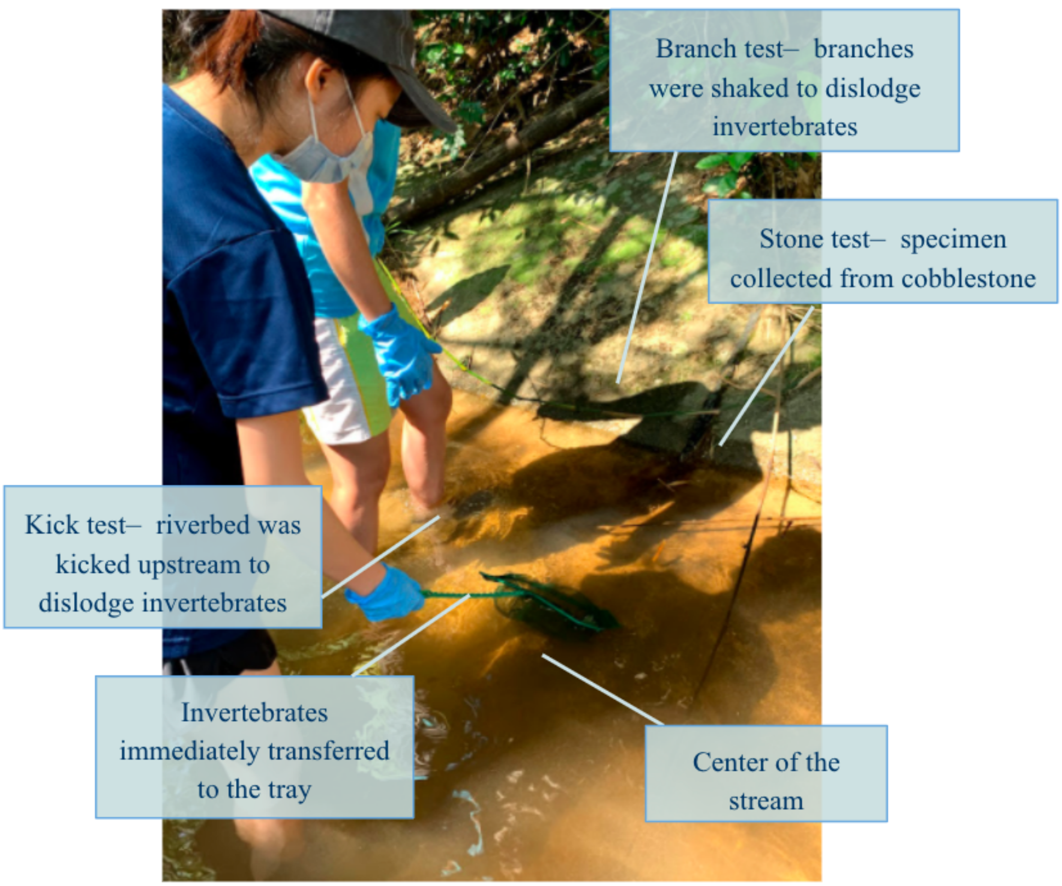

Figure 2.2 Kick Test

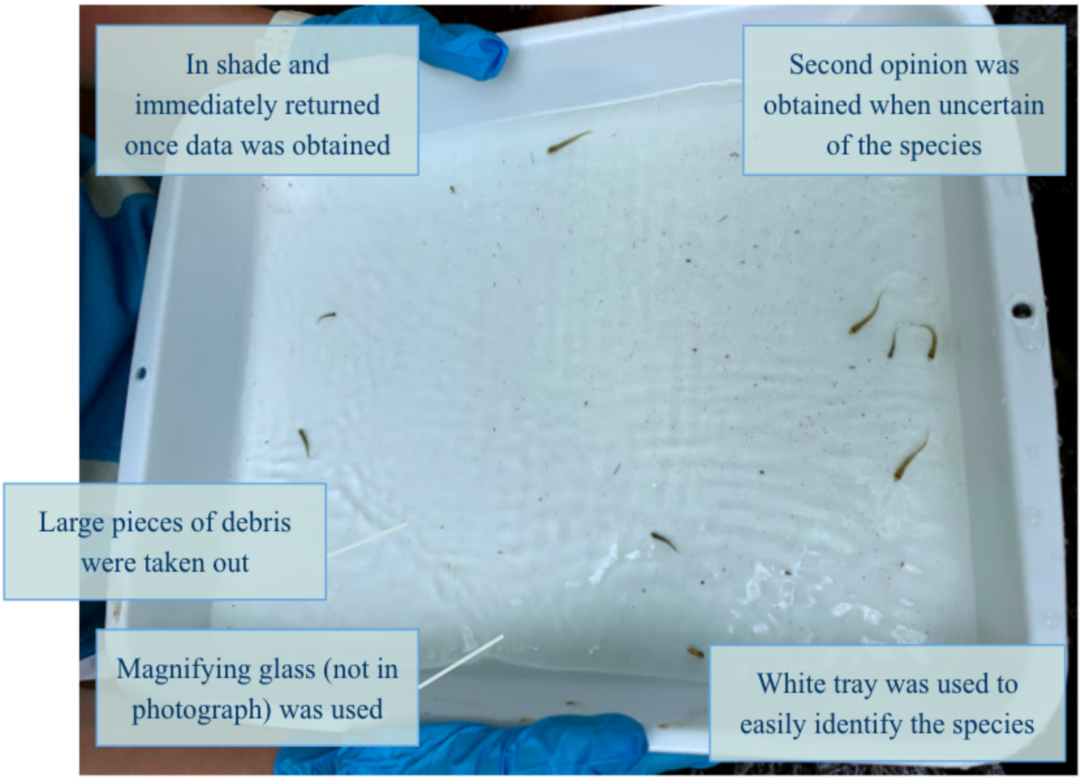

Figure 2.3 Measuring Species WQS

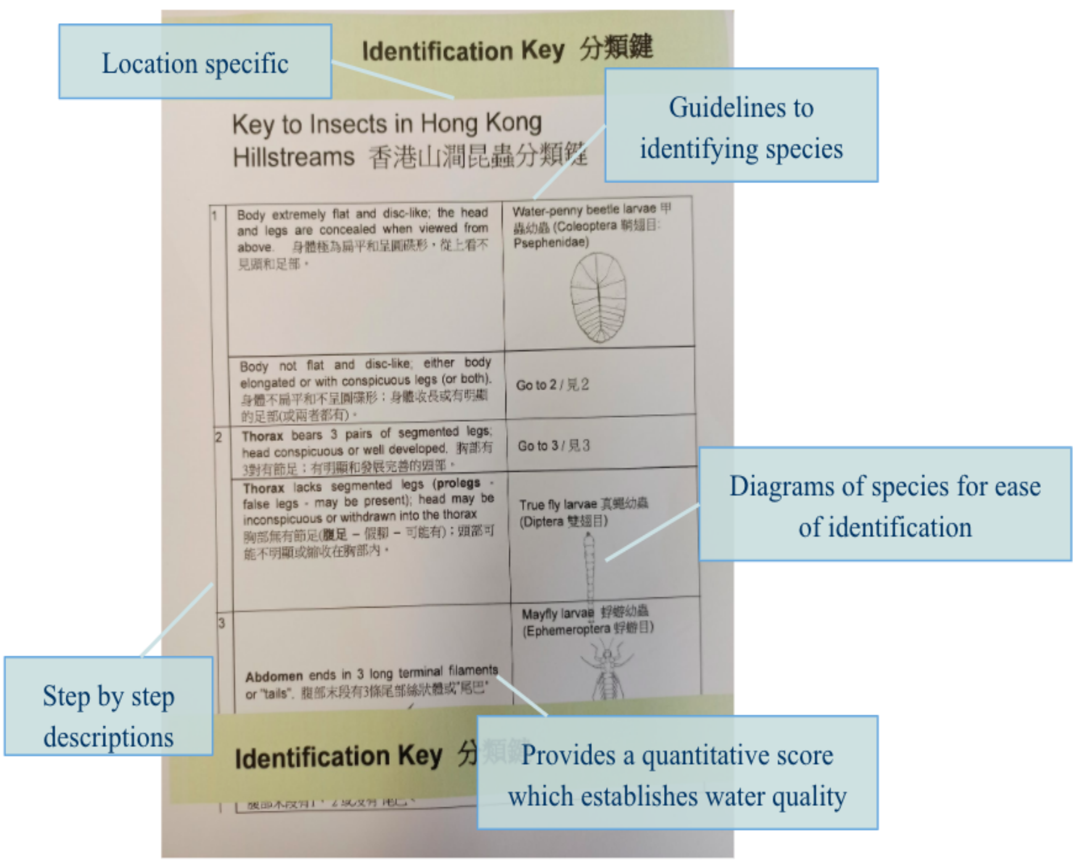

Figure 2.4 Species Identification Key

Riparian Index Assessments

Riparian index is a measure of the ecological condition of riparian vegetation, which is crucial in filtering sediments, retaining pollutants, and providing shelter for terrestrial and aquatic species. A lower riparian index score would reflect signs of human activity and pollution, indicating low levels of water quality.

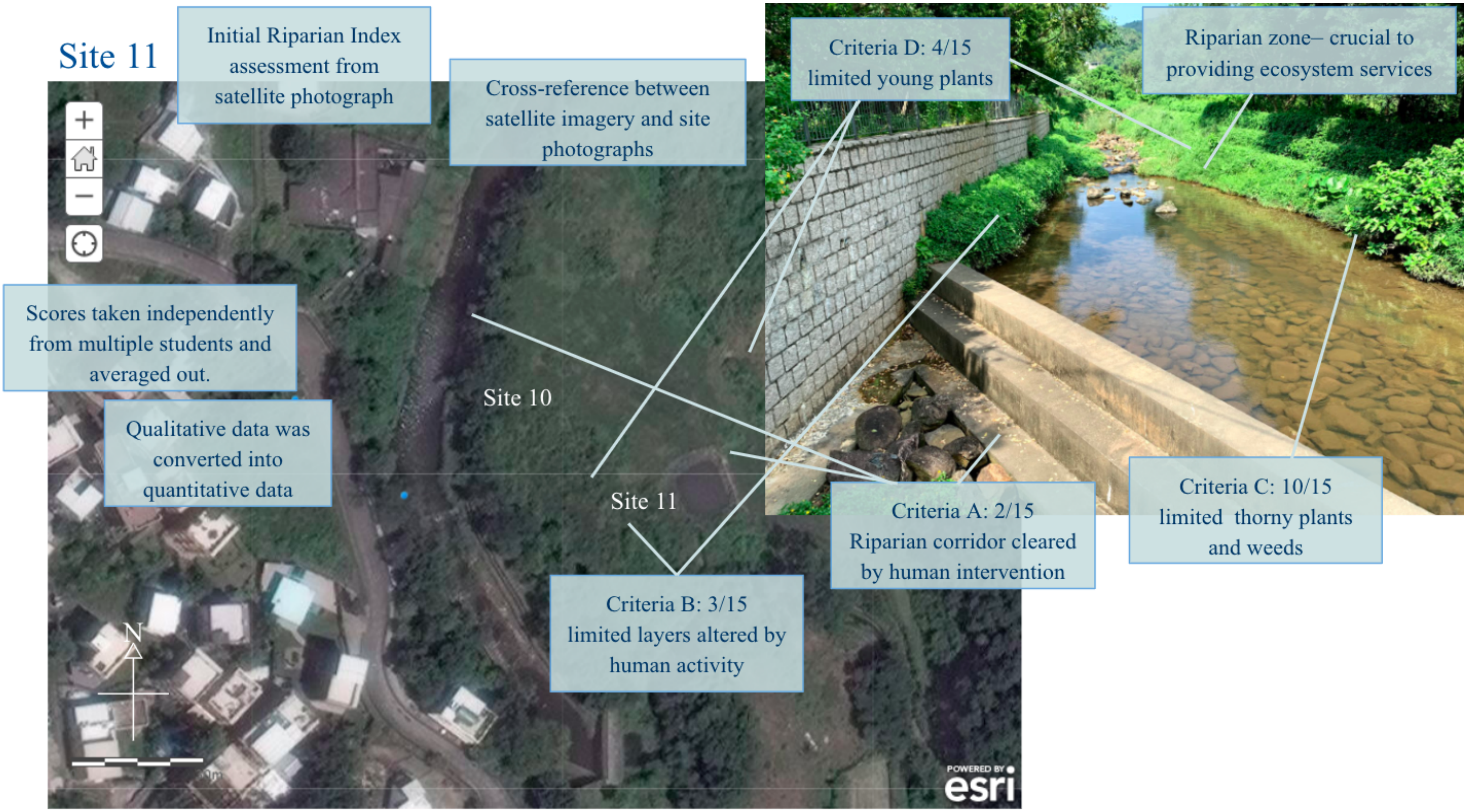

Figure 2.5 Riparian Index Assessment (Site 11)

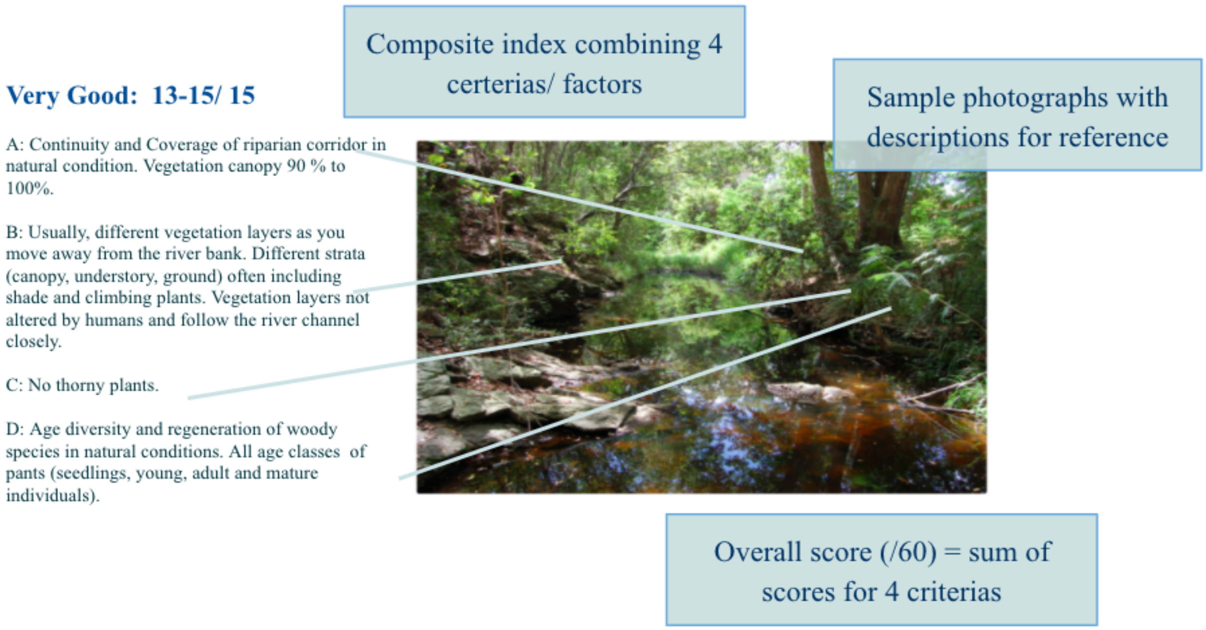

Figure 2.6 Sample Riparian Index Calculation Sheet

Measuring Levels of Dissolved Oxygen

As previously mentioned, dissolved oxygen is a major indicator of habitat availability for macroinvertebrates. Field photographs and observations will also be collected to identify factors influencing levels of dissolved oxygen, such as eutrophication.

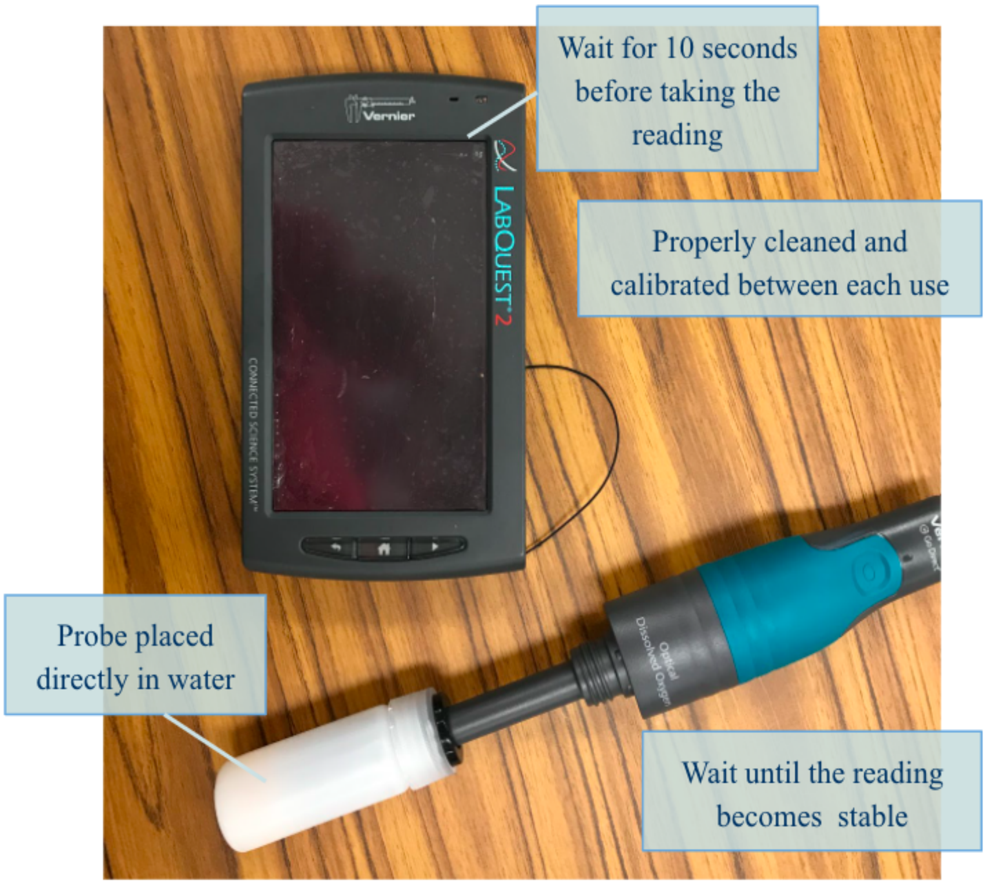

Figure 2.7 Dissolved Oxygen Meter

Collecting Chemical Data

Water samples were collected and tested for nitrates, phosphates, and dissolved oxygen. A sudden anomaly of such chemicals would indicate sources of pollution such as illegal dumping of fertilizers. Excessive nitrates would stimulate algae growth, which would indirectly cause oxygen deficiency and reduced biodiversity[7]. Similarly, excessive phosphate leads to eutrophication, which reduces levels of dissolved oxygen[8].

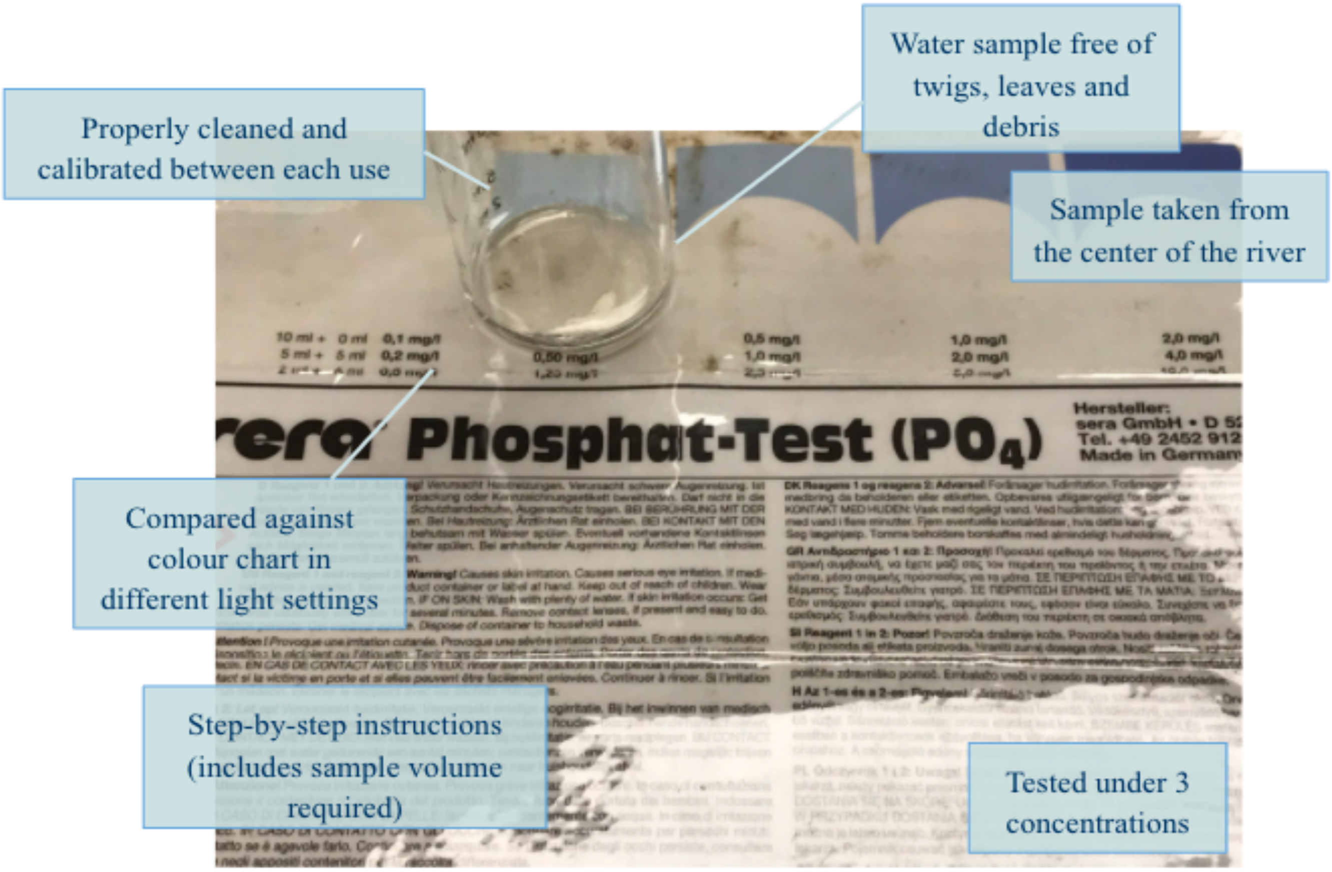

Figure 2.8 Results of Chemical Tests (phosphate PO_4)

[7] "Nitrates in rivers — European Environment Agency." 1 Mar. 2015, https://www.eea.europa.eu/data-and-maps/explore-interactive-maps/nitrate-in-rivers. Accessed: 9 Nov. 2020.

[8] "Phosphorus and Water - USGS." https://www.usgs.gov/special-topic/water-science-school/science/phosphorus-and-water. Accessed: 9 Nov. 2020.

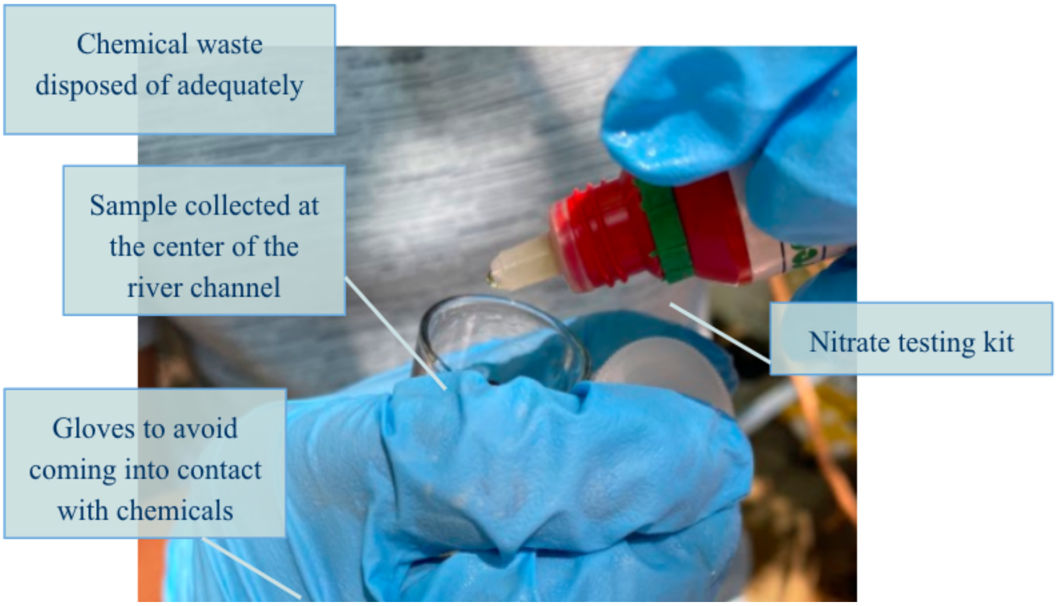

Figure 2.9 Testing for Presence of Nitrate (NO_3)

Secondary Data

To investigate factors which may influence downstream changes in river water quality, this will require secondary data sources. Maps and satellite photographs throughout this investigation (unless otherwise stated) are created using ArcGIS[9] software by Esri.

[9] "About ArcGIS | Mapping & Analytics Platform - Esri." https://www.esri.com/en-us/arcgis/about-arcgis/overview. Accessed: 3 Jan. 2021.

Primary Research Hypothesis - Water quality with Distance Downstream

H_1 - **Primary Research Hypothesis** - Water quality in the SMR will deteriorate with increasing distance downstream.

H_0 - **Null Hypothesis** - Water quality in the SMR is independent of distance downstream.

<u>Weighted Composite Index</u>

To examine the water quality of SMR, I designed a **Weighted Composite Index** based on multiple indices in acknowledgment that multiple variables interact with each other. Looking at the data (*Appendix 1*), there were no downstream changes in the levels of nitrates, hence I omitted it from my analysis. It is important to note that such data suggests a *lack of* point and nonpoint sources of pollution, such as due to illegal dumping of fertilizers.

Raw Data

To determine how to compose my index, I plotted a raw data graph *(Figure 3.1)*. I noticed that the species WQS fluctuated, suggesting that species WQS might be sensitive to changes in water quality. Thus, I decided to give it more importance in the index. Moreover, *Figure 3.1* shows that levels of phosphate in SMR *increases* with distance downstream (a positive correlation). As we know from earlier research that *higher* levels of phosphate indicate *lower* levels of water quality, it is important to process the data so that phosphate levels and water quality are positively correlated (a *higher* score reflects a *higher* water quality).

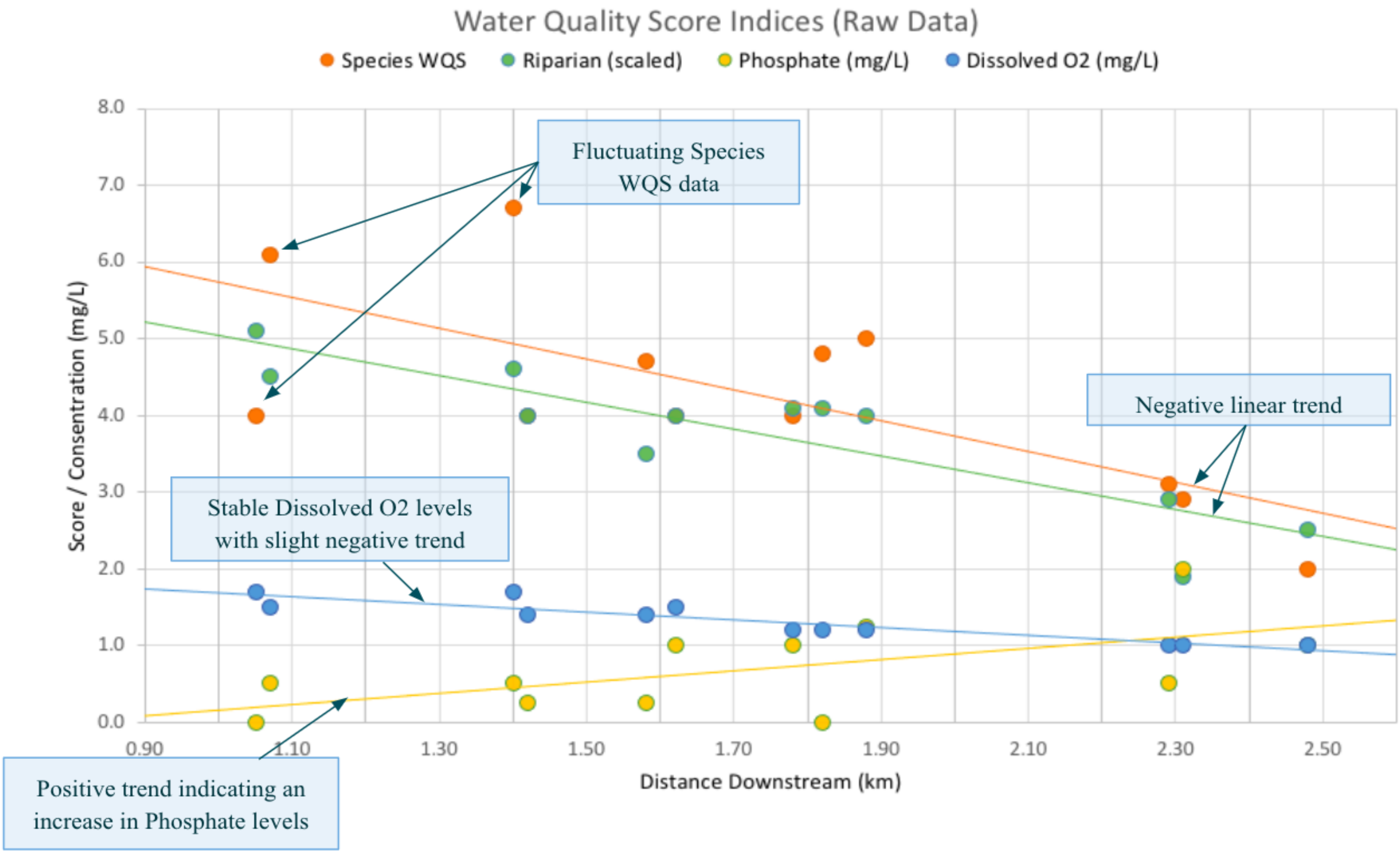

Figure 3.1 Raw data graph showing changes with distance downstream for different variable

Unweighted Composite Index

In order to create a weighted composite index for, I must first normalize the data. This is because variables measured at different scales do not contribute equally to an index, which creates bias. Min-max normalization was used, where I rescaled the data range to [0, 1].

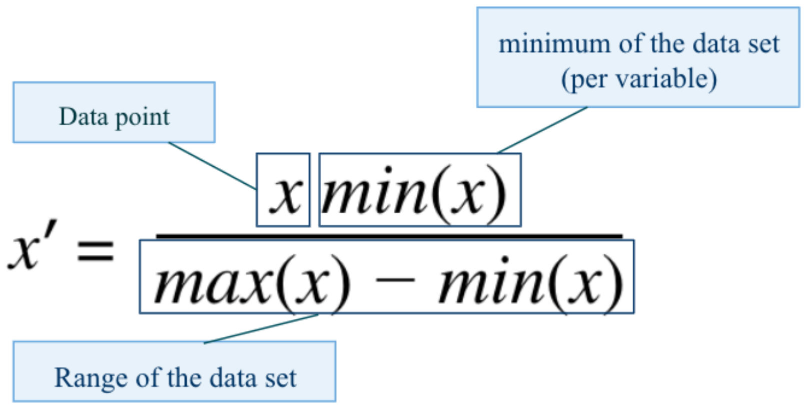

Figure 3.2 Min-Max Normalization[10]

I have also processed the data so that phosphate levels are *positively* correlated with water quality by simply subtracting the new value from 1. Afterwards, individual components were added together, and the data was rescaled so that the Unweighted Composite Index has a max score of 100 (*Appendix 2*).

[10] "Handbook on Constructing Composite Indicators - OECD." 21 Mar. 2005, https://www.oecd.org/sdd/42495745.pdf. Accessed: 1 Jan. 2021.

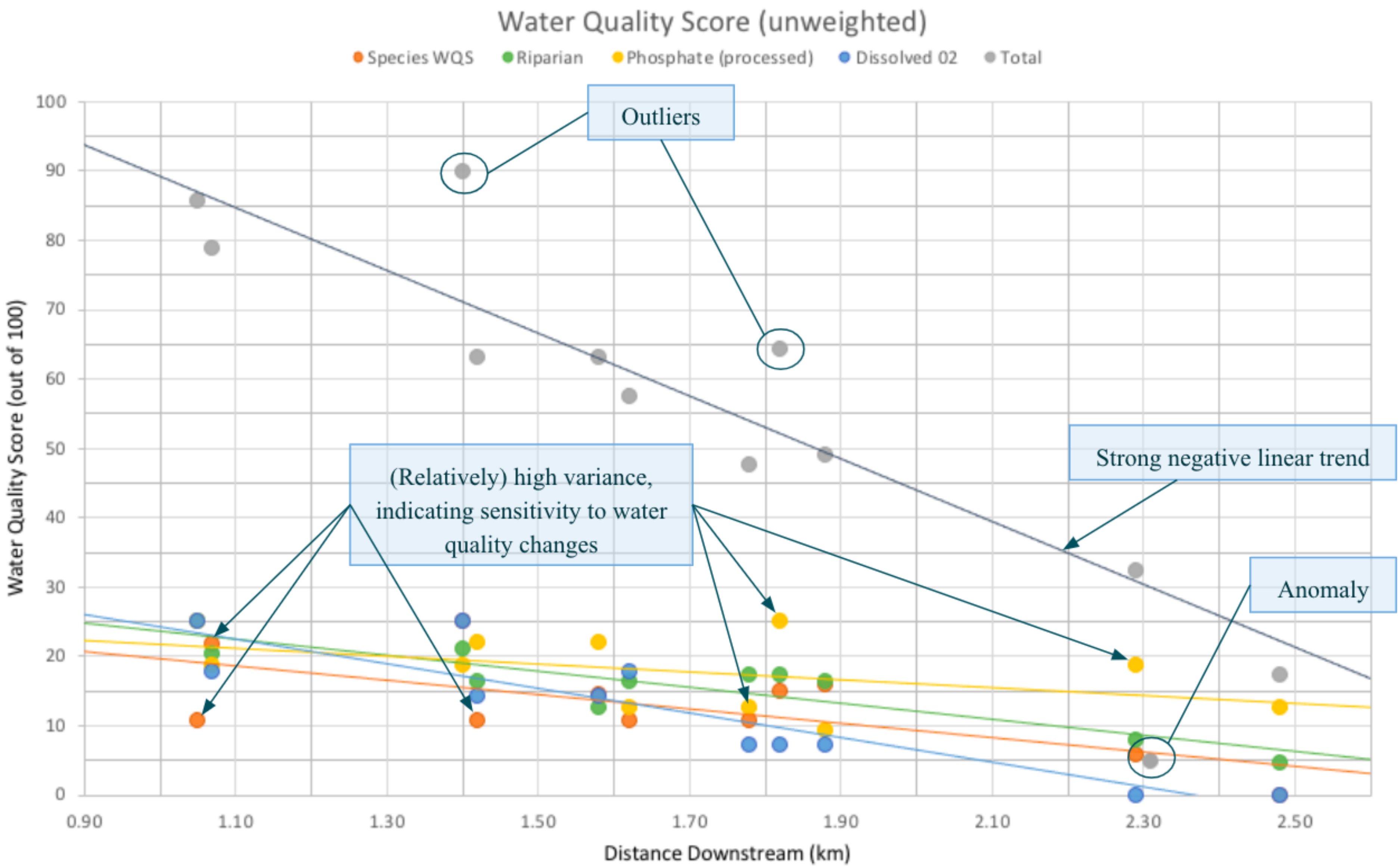

Figure 3.3 Scatter graph showing WQS (unweighted) and its respective variables (scaled)

With all variables on the same scale, the degree of change (trendline gradient) and correlation becomes more apparent. The composite index also reveals the anomaly [2.31, 4.8], which was removed from the data set to preserve the trendline. Potential reasons for the anomaly will be discussed later in this study. Additionally, outliers [1.40, 89.8] and [1.82, 64.2] are not considered as anomalies as they do not deviate massively. It is important to recognize that they skew and reduce the correlation coefficient (as they are still retained in the data set, as opposed to anomaly [2.31, 4.8]).

Weighting

I noticed that in addition to species WQS, phosphate levels also appear to fluctuate, suggesting that both variables might be sensitive to changes in water quality. Hence, I decided to give both a heavier weighting (× *1.25*). I have also assigned levels of dissolved oxygen a lighter weighting (× *0.75*), This is because levels of dissolved oxygen are in theory reflected in the species WQS (as explained in the introduction).

By assigning correlated variables a lighter weighting, this prevents double-counting and increases the sensitivity of my weighted composite index to different factors which might each influence water quality in a different way[11]. Whether there exists an actual correlation between levels of dissolved oxygen and species WQS will be the focus of my Secondary Research Hypothesis.

In a similar way to the unweighted WQS, individual components were then added together after weighting and the data was rescaled so that the weighted composite index has a max score of 100 (*Appendix 3*).

[11] "Handbook on Constructing Composite Indicators - OECD." 21 Mar. 2005, https://www.oecd.org/sdd/42495745.pdf. Accessed: 31 Dec. 2020.

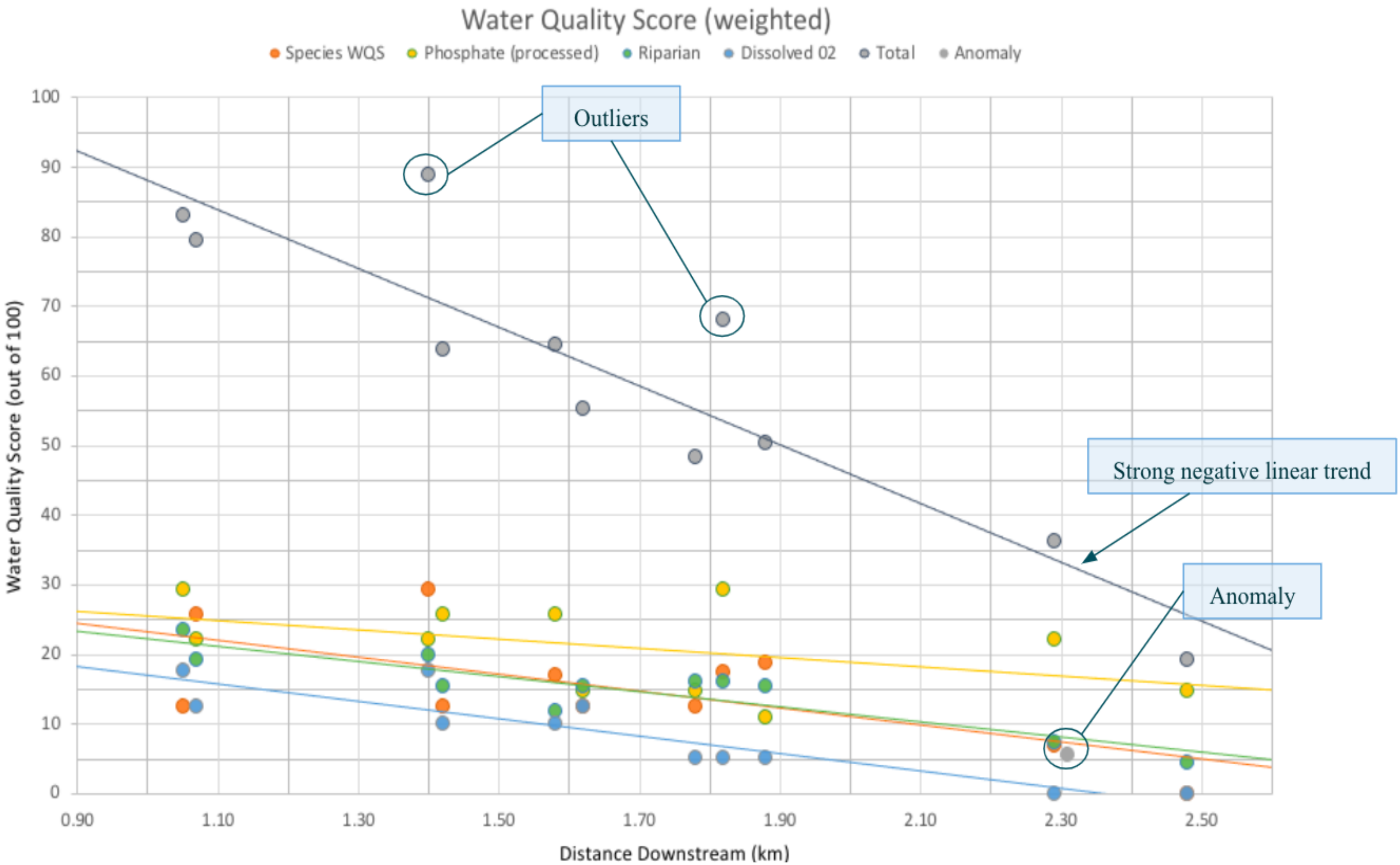

Figure 3.4 Scatter graph showing WQS (weighted) and its respective variables (scaled)

At first glance, the scatter graph for the weighted composite index appears to be largely similar to the unweighted one. However, the differences will be better reflected when you consider the ratio between different variables (*Figure 3.5*)

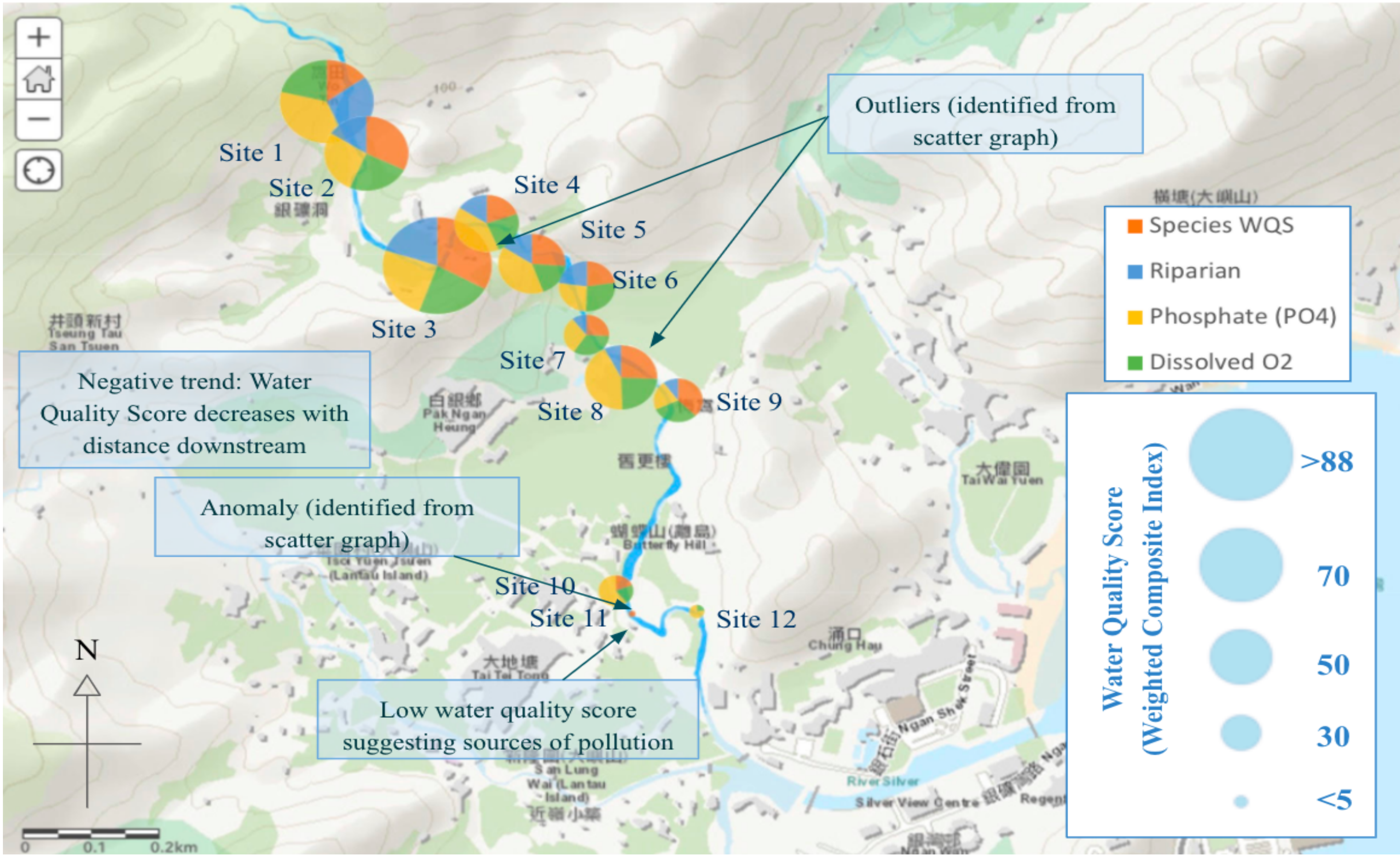

Figure 3.5 Map with magnitude indicating WQS (weighted) and relative ratio of variables

Figure 3.5 provides us with a spatial understanding of WQS in the SMR. WQS appears to decrease with distance downstream, as noted in Figure 3.4. The map suggests that this could be due to the presence of rural settlements, which serves as major point and nonpoint sources of pollution. It is interesting to note that as the river progresses downstream, in particular at Sites 10-12, the relative contribution from the riparian index decreases almost entirely. This indicates a presence of human intervention on the riparian corridor, suggesting potential nonpoint sources of pollution.

Inferential Statistics

Initial descriptive techniques have revealed a general negative trend between WQS and distance downstream, supporting my primary research hypothesis. As an alternative to Spearman's Rank Correlation Coefficient (SRCC), the Product-Moment Correlation Coefficient (PMCC) was employed to determine the strength and significance of the correlation. This was because ratio-level variables (WQS and distance downstream) were measured, sample size was sufficient and that the relationship was determined to be linear (via scatter graph, *Figure 3.3*). Moreover, PMCC is more statistically powerful due to how SRCC reduces the level of measurement from ratio-level to ordinal-level, making it less sensitive to outliers. As usual, anomaly [2.31, 4.8] was removed from the data set.

PMCC showed a statistically significant result: $r(10) = -0.90$, $p < 0.01$ (*Appendix 4*). Since the probability of obtaining this result by chance is less than 0.01, the study successfully rejects the null hypothesis: There is a strong negative correlation between water quality in the SMR and distance downstream.

Possible Reasons

The potential reasons for this strong negative correlation can be explained through the initial secondary research and satellite photographs (in the *Introduction,* in particular, *Figure 1.3*) where numerous point and nonpoint sources of pollution were identified. *Figures 3.6-9* elaborates on this.

Figure 3.6 Annotated map explaining results obtained (Sites 1-2)

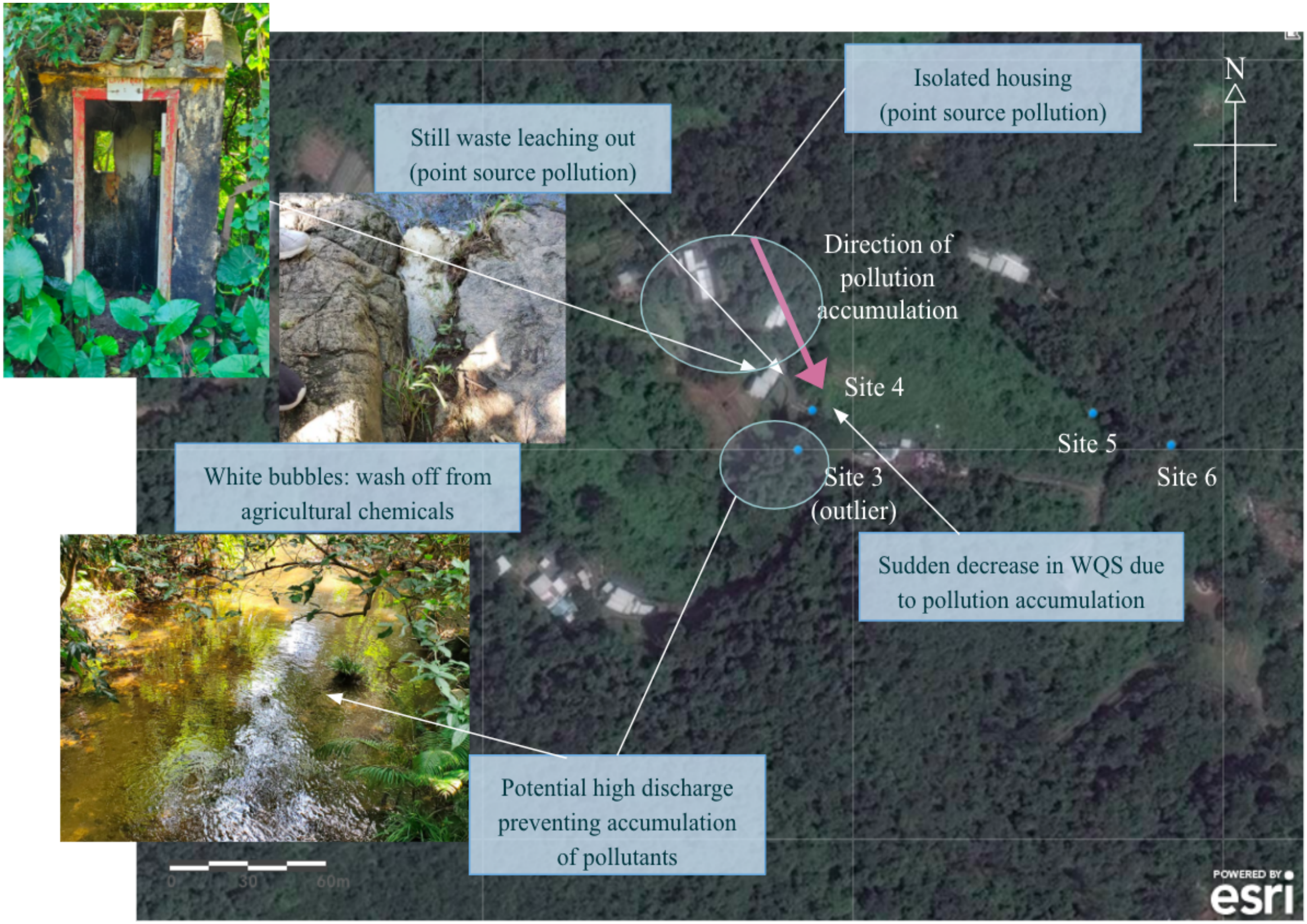

Figure 3.7 Annotated map explaining results obtained (Sites 3-6)

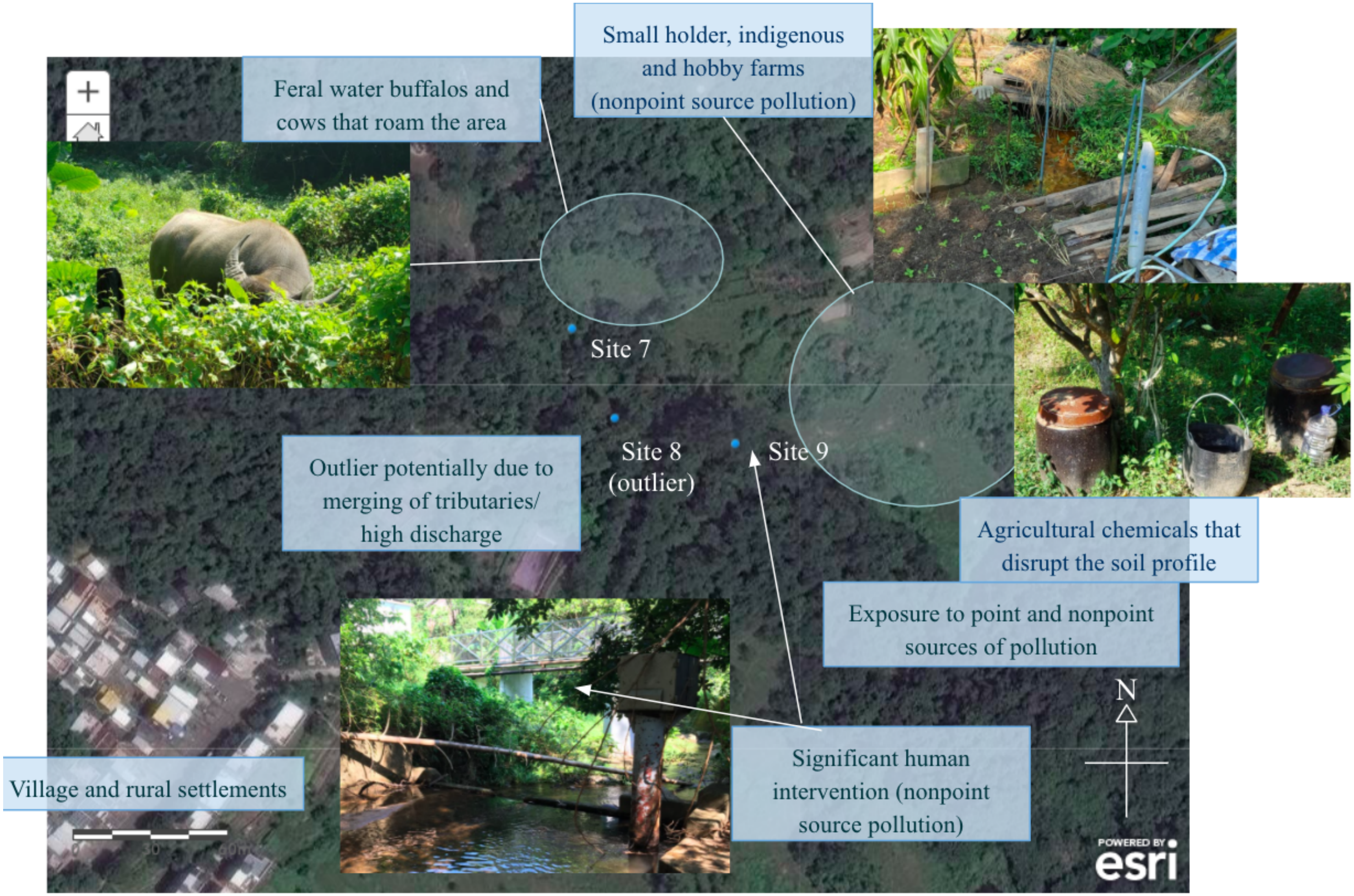

Figure 3.8 Annotated map explaining results obtained (Sites 7-9)

Figure 3.9 Annotated map explaining results obtained (Sites 10-12

Satellite photographs and field observations have indicated the presence of agricultural land use, in particular smallholder, indigenous, and hobby farms. Fertilizers applied to the field creates nonpoint sources of pollution. We have observed that this is particularly significant in SMR as smallholders tend to not follow government guidelines and lack an understanding of fertilizer damage (*Figure 3.8)*. Moreover, isolated housing and rural settlements along the river would result in an accumulation of pollution downstream (*Figure 3.7)*, which explains the sudden decrease in WQS after Site 3. Additionally, feral water buffalos and cows that roam the area would result in the deposition of animal waste, contributing to the deteriorating water quality (*Figure 3.8-9)*. The anomaly present at Site 11 could potentially be due to its low discharge (as indicated by the presence of human activity), resulting in an accumulation of pollutants. The influence of discharge on the concentration of pollutants could be a point of investigation in the future.

Secondary Research Hypothesis - Dissolved Oxygen and Species WQS

$\boldsymbol{H_1}$ - **Secondary Research Hypothesis** - As dissolved oxygen levels increase, species WQS increases

$\boldsymbol{H_0}$ - **Null Hypothesis** - There will be no significant relationship between dissolved oxygen levels and species WQS in the SMR

Figure 3.10 Dual series graph showing the downstream changes of Species WQS and Dissolved Oxygen Levels

Figure 3.10 shows a strong negative linear trend for both species WQS and dissolved oxygen levels, suggesting a probable relationship between the two. However, the fluctuating species WQS data and high variance challenges the strength of the correlation. A raw data graph between dissolved oxygen levels and species WQS is necessary to determine the nature of the relationship.

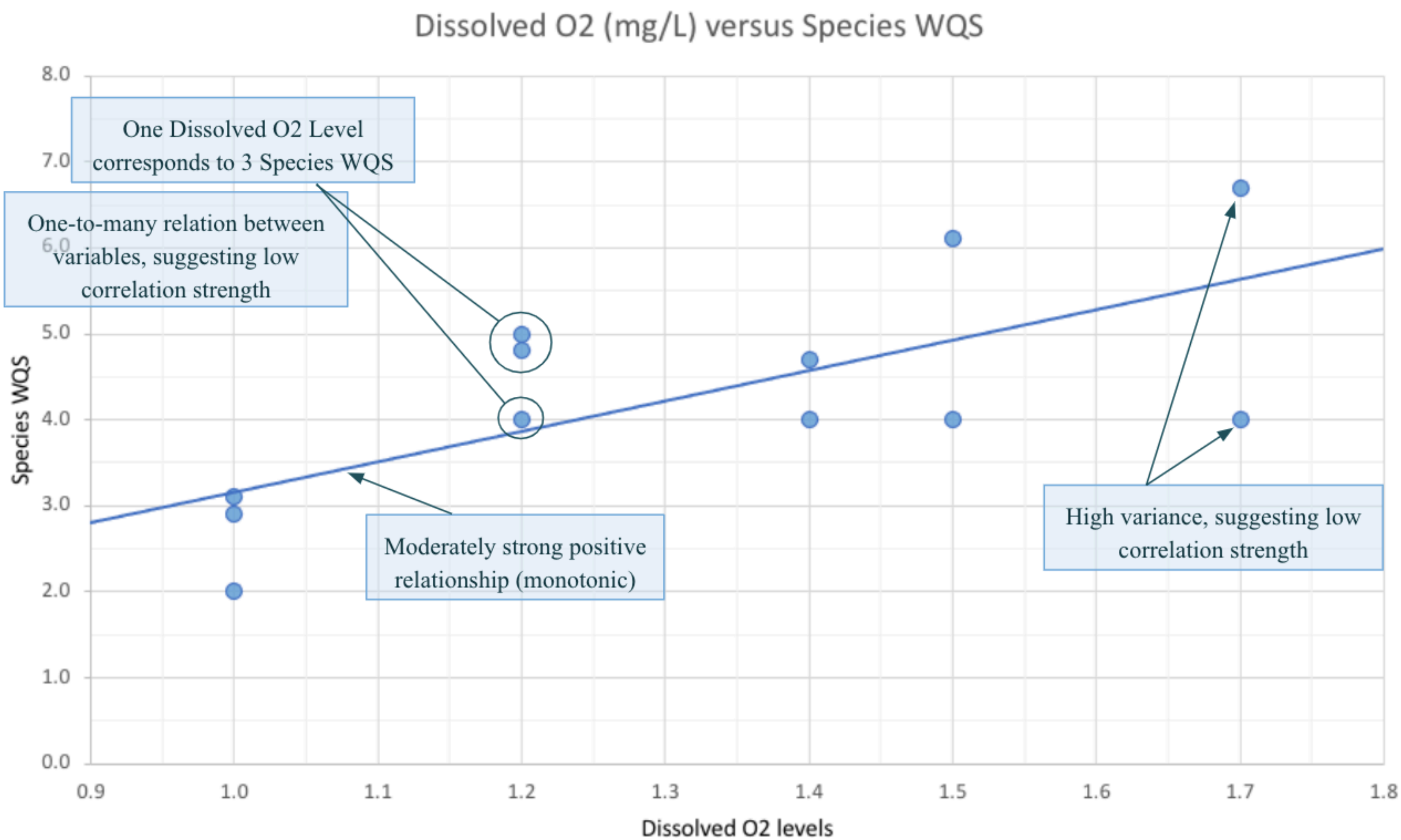

Figure 3.11 Raw data graph showing the relationship between Species WQS and Dissolved Oxygen Levels (mg/L)

Figure 3.11 revealed a moderately strong positive trend between species WQS and dissolved oxygen. However, the correlation appears to be weak due to the one-to-many relation between variables and high variance.

Inferential Statistics

As the relationship could be non-linear (suggested by *Figure 3.11*), SRCC is used due to its sensitivity to monotonic relationships (as opposed to linear). SRCC showed a statistically significant result: $r_s(10) = 0.64$, $p < 0.05$ (*Appendix 5*). Since the probability of obtaining this result by chance is less than 0.05, the study successfully rejects the null hypothesis: There is a moderately strong positive correlation between dissolved oxygen levels and species WQS.

It is important to note that although the positive correlation was of moderate strength, the one-to-many relationship suggests a lack of causation between the two variables-- there are external factors responsible for the relationship. Nevertheless, such findings reveal the interrelationships between dissolved oxygen levels and species WQS, demonstrating the importance of dissolved oxygen for biological processes.

Conclusion and Evaluation

This study aimed to answer the research question: **How does water quality in the SMR change with distance downstream?**

Summary of Results

- Water quality in the SMR deteriorates with increasing distance downstream.
- As dissolved oxygen levels increase, species WQS increases.

Primary Hypothesis - Water Quality and Distance Downstream

Water quality was operationalized as a weighted composite index consisting of species WQS, riparian score, dissolved oxygen levels, and phosphate levels (*Figure 3.4-5*). In accordance with my hypothesis, the study found a strong and statistically significant negative correlation between water quality in the SMR and distance downstream. This is consistent with The Bradshaw Model, which states that in theory, load quantity and capacity is expected to increase with distance downstream, allowing for more pollution to accumulate.

Secondary Hypothesis - Species WQS and Dissolved Oxygen levels

The study determined a moderately strong positive correlation between dissolved oxygen levels and species WQS. This is in accordance with my hypothesis, which explains the interrelationships between habitat availability for macroinvertebrates and levels of dissolved oxygen.

Evaluation

Limitation	Impact	Method of Improvement
The study does not account for geographical factors	Rainfall prior to data collection would affect the discharge of the river, which prevents the accumulation of pollutants thus influencing the reliability of the data.	Any rainfall a few days prior to the data collection should be noted. This allows us to account for increased discharge due to rainfall thus increasing the reliability of the study.
Sample size was small and locations were not equidistant	The lack of equidistant locations greatly diminishes data accuracy as we could only collect limited data from specific locations due to access restrictions. The limited data is likely to be unreliable and does not provide us with a holistic understanding of the entire river.	Ideally, data should be collected on equally spaced-out locations, allowing us to improve on the accuracy of our findings and make better generalizations.
Weightings for the Weighted Composite Index were subjective	This could heavily influence the results of our findings. For instance, if a variable that strongly deviated from the trend was assigned a heavier weight, this could influence the correlation and statistical significance of our findings, potentially (and incorrectly) refuting the hypothesis.	The lack of objectivity in the Weighted Composite Index does not mean that we should reject its validity. As long as the process was justified and transparent, this could be useful in modeling and approximating the real conditions of the river.
Correlation between variables does not imply causation	Despite the correlation between species WQS and dissolved oxygen levels, the one-to-many relationship suggests a lack of causation between the two variables-- there are external factors responsible for the relationship.	Additional data, such as river discharge and chemical data could be collected to identify such external factors, providing us with a more holistic understanding of the river.

Bibliography

Maps and satellite images throughout this investigation (unless otherwise stated) were created using ArcGIS software by Esri, www.esri.com.

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"River Water Quality in Hong Kong - EPD." https://www.epd.gov.hk/epd/misc/river_quality/1986-2005/eng/6_lantau_content.htm. Accessed: 22 June. 2020.

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"Nitrates in rivers — European Environment Agency." 1 Mar. 2015, https://www.eea.europa.eu/data-and-maps/explore-interactive-maps/nitrate-in-rivers. Accessed: 9 Nov. 2020.

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"Table of Critical Values: Pearson Correlation - Statistics ...." https://www.statisticssolutions.com/table-of-critical-values-pearson-correlation/. Accessed: 3 Jan. 2021.

"Spearman's Rank Correlation Coefficient." 1 Sept. 2020, https://geographyfieldwork.com/SpearmansRank.htm. Accessed: 3 Jan. 2021.

"Significance of Spearman's Rank Correlation Coefficient." 1 Sept. 2020, https://geographyfieldwork.com/SpearmansRankSignificance.htm. Accessed: 3 Jan. 2021.

Appendices

Appendix 1: Raw Data Table

Site	Latitude	Longitude	Distance downstream (km)	Species WQS	Dissolved O_2 (mg/L)	Riparian Score	Nitrate NO_2	Nitrate NO_3	Phosphate PO_4(mg/L)
1	22.275899	113.988312	1.05	4.0	1.7	51	0	0	0.00
2	22.275705	113.988406	1.07	6.1	1.5	45	0	0	0.50
3	22.273843	113.989824	1.40	6.7	1.7	46	0	0	0.50
4	22.273976	113.989873	1.42	4.0	1.4	40	0	0	0.25
5	22.273965	113.990918	1.58	4.7	1.4	35	0	0	0.25
6	22.273858	113.991208	1.62	4.0	1.5	40	0	0	1.00
7	22.272771	113.991905	1.78	4.0	1.2	41	0	0	1.00
8	22.272458	113.992066	1.82	4.8	1.2	41	0	0	0.00
9	22.272370	113.992521	1.88	5.0	1.2	40	0	0	1.25
10	22.268915	113.992178	2.29	3.1	1.0	29	0	0	0.50
11	22.268721	113.992419	2.31	2.9	1.0	19	0	0	2.00
12	22.268868	113.993495	2.48	2.0	1.0	25	0	0	1.00

Appendix 2: Unweighted Composite Index Calculations

fx =(AL5-2)/4.7

AJ	AK	AL	AM	AN	AO	AP
	Distance dov	Species WQS	Dissolved O2 (m	Riparian score	Phosphate (mg/L)	
1	1.05	4.0	1.7	51	0.00	
2	1.07	6.1	1.5	45	0.50	
3	1.40	6.7	1.7	46	0.50	
4	1.42	4.0	1.4	40	0.25	
5	1.58	4.7	1.4	35	0.25	
6	1.62	4.0	1.5	40	1.00	
7	1.78	4.0	1.2	41	1.00	
8	1.82	4.8	1.2	41	0.00	
9	1.88	5.0	1.2	40	1.25	
10	2.29	3.1	1.0	29	0.50	
11	2.31	2.9	1.0	19	2.00	
12	2.48	2.0	1.0	25	1.00	
Range:	Range:	4.7	0.7	32.0	2	
Minimum	Minimum	2	1	19	0	
Normalized	Distance dov	Species WQS	Dissolved O2 (m	Riparian score	Phosphate (mg	Phosphate (scaled)
1	1.05	0.43	1.00	1.00	0.00	1.00
2	1.07	0.87	0.71	0.81	0.25	0.75
3	1.40	1.00	1.00	0.84	0.25	0.75
4	1.42	0.43	0.57	0.66	0.13	0.88
5	1.58	0.57	0.57	0.50	0.13	0.88
6	1.62	0.43	0.71	0.66	0.50	0.50
7	1.78	0.43	0.29	0.69	0.50	0.50
8	1.82	0.60	0.29	0.69	0.00	1.00
9	1.88	0.64	0.29	0.66	0.63	0.38
10	2.29	0.23	0.00	0.31	0.25	0.75
11	2.31	0.19	0.00	0.00	1.00	0.00
12	2.48	0.00	0.00	0.19	0.50	0.50

Out of 100	Distance do	Species WQS	Dissolved O2 (m	Riparian score	Phosphate (m	Phosphate (s	Sum
1	1.05	10.6	25.0	25.0		25.0	85.6
2	1.07	21.8	17.9	20.3		18.8	78.7
3	1.40	25.0	25.0	21.1		18.8	89.8
4	1.42	10.6	14.3	16.4		21.9	63.2
5	1.58	14.4	14.3	12.5		21.9	63.0
6	1.62	10.6	17.9	16.4		12.5	57.4
7	1.78	10.6	7.1	17.2		12.5	47.5
8	1.82	14.9	7.1	17.2		25.0	64.2
9	1.88	16.0	7.1	16.4		9.4	48.9
10	2.29	5.9	0.0	7.8		18.8	32.4
11	2.31	4.8	0	0		0	4.8
12	2.48	0.0	0.0	4.7		12.5	17.2

Appendix 3: Weighted Composite Index Calculations

fx =AL50*(100/4.25)

AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
9	1.88	16.0	7.1	16.4		9.4	48.9		
10	2.29	5.9	0.0	7.8		18.8	32.4		
11	2.31	4.8	0	0		0	4.8		
12	2.48	0.0	0.0	4.7		12.5	17.2		
	Distance dov	Species WQS	Dissolved O2 (m	Riparian score	Phosphate (mg	Phosphate (scaled)			
Scaled		*1.25	*0.75	*1		*1.25			
1	1.05	0.53	0.75	1.00		1.25			
2	1.07	1.09	0.54	0.81		0.94			
3	1.40	1.25	0.75	0.84		0.94			
4	1.42	0.53	0.43	0.66		1.09			
5	1.58	0.72	0.43	0.50		1.09			
6	1.62	0.53	0.54	0.66		0.63			
7	1.78	0.53	0.21	0.69		0.63			
8	1.82	0.74	0.21	0.69		1.25			
9	1.88	0.80	0.21	0.66		0.47			
10	2.29	0.29	0.00	0.31		0.94			
11	2.31	0.24	0.00	0.00		0.00			
12	2.48	0.00	0.00	0.19		0.63			
	Distance dov	Species WQS	Dissolved O2 (m	Riparian score	Phosphate (mg	Phosphate (scaled)		Sum	
Out of 100	*(100/4.25)								
1	1.05	12.5	17.6	23.5		29.4		83.10	
2	1.07	25.7	12.6	19.1		22.1		79.44	
3	1.40	29.4	17.6	19.9		22.1		88.97	
4	1.42	12.5	10.1	15.4		25.7		63.78	
5	1.58	16.9	10.1	11.8		25.7		64.48	
6	1.62	12.5	12.6	15.4		14.7		55.27	
7	1.78	12.5	5.0	16.2		14.7		48.44	
8	1.82	17.5	5.0	16.2		29.4		68.15	
9	1.88	18.8	5.0	15.4		11.0		50.29	
10	2.29	6.9	0.0	7.4		22.1		36.30	
11	2.31	5.6	0.0	0.0		0.0		5.63	
12	2.48	0.0	0.0	4.4		14.7		19.12	

Appendix 4: PMCC Calculations (WQS and distance downstream)

PMCC Formula[12]:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - mean(x))(y_i - mean(y))}{\sqrt{\sum_{i=1}^{n}(x_i - mean(x))^2} \cdot \sqrt{\sum_{i=1}^{n}(y_i - mean(y))^2}}$$

Where:

- n is the sample size
- x_i, y_i are the x and y component of the i_{th} data point
- *mean(x)* and *mean(y)* are the mean of x components and mean of y components of the data set respectively.

[12] "Pearson Correlation Coefficient - Magoosh Statistics Blog." 9 Apr. 2018, https://magoosh.com/statistics/pearson-correlation-coefficient/. Accessed: 3 Jan. 2021.

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=BF17/SQRT(BC17*BD17)

AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF
	Distance do	Composite Index		*x - mean(x)*	*y - mean(y)*		*(x - mean(x))^2*	(y - mean(y))^2		x - mean(x) * y -
1	1.05	83.10		-0.675	27.852		0.456	0.456		-18.800
2	1.07	79.44		-0.655	24.193		0.429	0.429		-15.846
3	1.40	88.97		-0.325	33.723		0.106	0.106		-10.960
4	1.42	63.78		-0.305	8.533		0.093	0.093		-2.602
5	1.58	64.48		-0.145	9.233		0.021	0.021		-1.339
6	1.62	55.27		-0.105	0.023		0.011	0.011		-0.002
7	1.78	48.44		0.055	-6.807		0.003	0.003		-0.374
8	1.82	68.15		0.095	12.903		0.009	0.009		1.226
9	1.88	50.29		0.155	-4.957		0.024	0.024		-0.768
10	2.29	36.30		0.565	-18.947		0.319	0.319		-10.705
11	2.31	5.63		0.585	-49.617		0.342	0.342		-29.026
12	2.48	19.12		0.755	-36.128		0.570	0.570		-27.276
Mean:	1.725	55.247				Sum:	2.383	7019.783		-116.472
	PMCC r value:		r = -116.475 / √((2.383)(7019.783))							
			-0.900529							

Table of Critical Values (PMCC)[13]:

Table of Critical Values: Pearson Correlation

	1-tailed		
	0.05	0.025	0.005
	2-tailed Degrees of Freedom = N-2		
N	**0.1**	**0.05**	**0.01**
1	0.988	0.997	0.999
2	0.900	0.950	0.990
3	0.805	0.878	0.959
4	0.729	0.811	0.917
5	0.669	0.754	0.875
6	0.621	0.707	0.834
7	0.584	0.666	0.798
8	0.549	0.632	0.765
9	0.521	0.602	0.735
10	0.497	0.576	0.708
11	0.476	0.553	0.684
12	0.458	0.532	0.661
13	0.441	0.514	0.641
14	0.426	0.497	0.623
15	0.412	0.482	0.606
16	0.400	0.468	0.590

Where $degrees\ of\ freedom = number\ of\ pairs\ in\ the\ sample - 2$

The critical value for PMCC at $p = 0.01$ for $n = 12$ is 0.708. Since 0.90 > 0.708, the result is statistically significant.

[13] "Table of Critical Values: Pearson Correlation - Statistics ...." https://www.statisticssolutions.com/table-of-critical-values-pearson-correlation/. Accessed: 3 Jan. 2021.

Appendix 5: SRCC Calculations (Species WQS and Dissolved Oxygen Levels)

SRCC Formula[14]:

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^{\,2}}{n(n^2-1)}$$

Where:

- d_i is the difference in rank of the i_{th} data point
- n is the number of pairs in a sample

fx =1- ((6*102)/(12*(144-1)))

AV	AW	AX	AY	AZ	BA	BB	BC
	Species WQ	Dissolved O2 (mg/L)		Species WQS Rank	Dissolved O2 Rank	Difference in Rank	d^2
1	4.0	1.7		5.5	11.5	-6	36
2	6.1	1.5		11	9.5	1.5	2.25
3	6.7	1.7		12	11.5	0.5	0.25
4	4.0	1.4		5.5	7.5	-2	4
5	4.7	1.4		8	7.5	0.5	0.25
6	4.0	1.5		5.5	9.5	-4	16
7	4.0	1.2		5.5	5	0.5	0.25
8	4.8	1.2		9	5	4	16
9	5.0	1.2		10	5	5	25
10	3.1	1.0		3	2	1	1
11	2.9	1.0		2	2	0	0
12	2.0	1.0		1	2	-1	1
						Sum:	102
	SRCC r value:		r=1- (6*102)/12(144-1)				
			0.6433566				

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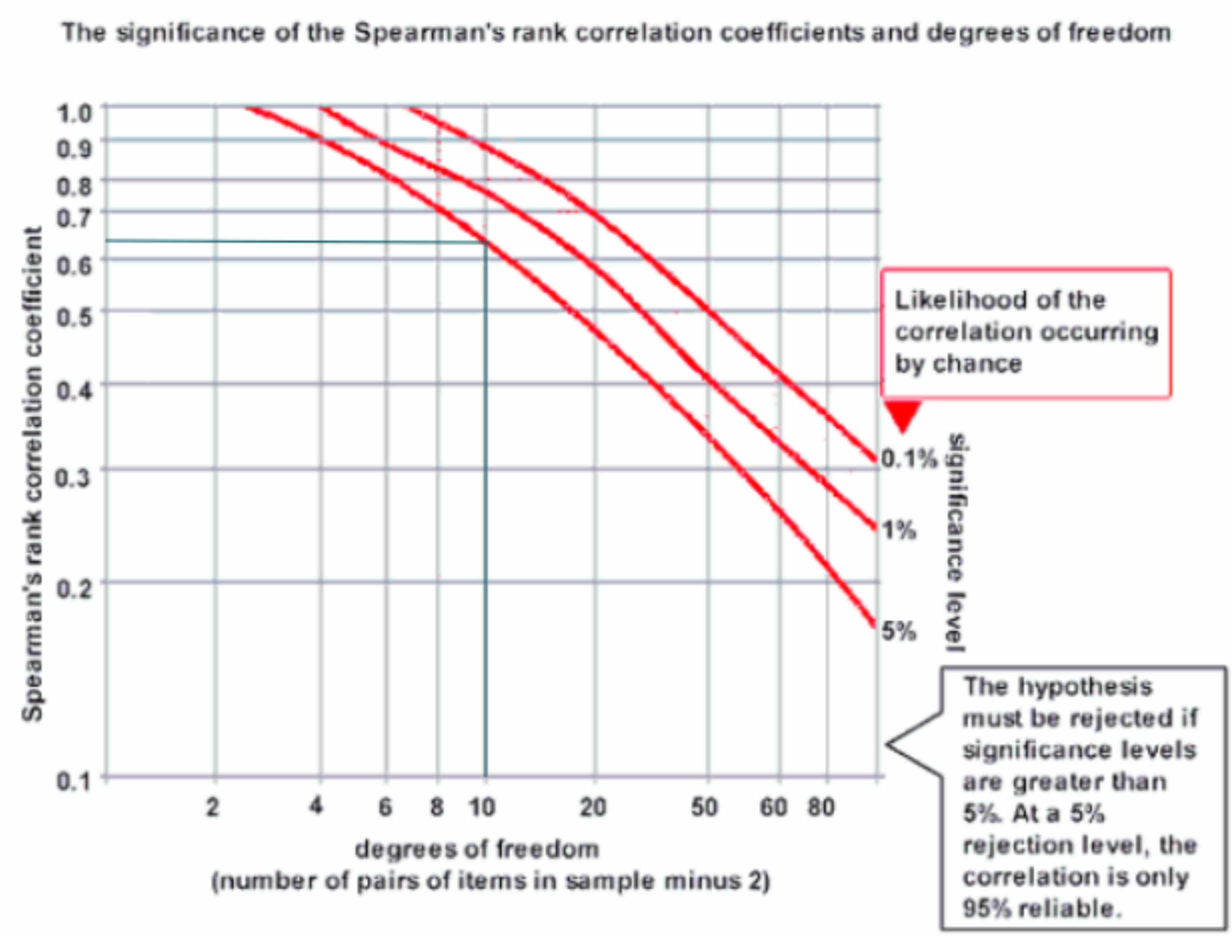
[14] "Spearman's Rank Correlation Coefficient." 1 Sept. 2020, https://geographyfieldwork.com/SpearmansRank.htm. Accessed: 3 Jan. 2021.

Table of Critical Values (SRCC)[15]:



SRCC showed a statistically significant result: $r_s(10) = 0.64$, $p < 0.05$. Since the probability of obtaining this result by chance is less than 0.05, the result is statistically significant.

[15] "Significance of Spearman's Rank Correlation Coefficient." 1 Sept. 2020, https://geographyfieldwork.com/SpearmansRankSignificance.htm. Accessed: 3 Jan. 2021.