

# Inverse Distance Weighting as an alternative interpolation method to create radiometric maps of natural radionuclide concentrations using QGIS

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**Abstract:** A previous study by the authors illustrated the distribution of naturally occurring radionuclides, i.e., potassium ( $K^{40}$ ), thorium ( $Th^{232}$ ), and uranium ( $U^{238}$ ), in the sediment of the Berg River estuary. The study also described the Delta Underwater Gamma detection System (DUGS) and its usage to measure the concentrations of these natural radionuclides. It also proposed a novel radiometric mapping technique with QGIS and, more importantly, highlighted the geospatial process through Kernel Density Estimation (KDE) to create radiometric maps. The present study used the same data and a similar design but proposed the use of the Inverse Distance Weighted (IDW) interpolation method in QGIS to display natural radionuclide concentrations. The radiometric maps created in the previous study using the KDE technique created smooth and visually attractive maps. However, the IDW method is an exact interpolation method that predicts a value at a sampling location that is identical to the observed value. This is a requirement for the analysis of natural radionuclide concentrations in sediments. However, the effectiveness of the interpolation methods was evaluated using SPSS statistics software. First, probability-probability (P-P) plots were produced for each interpolation method. Secondly, descriptive regression statistics, including 'goodness-of-fit', Analysis-of-Variance (ANOVA), coefficients, and residuals were evaluated for both the IDW and KDE interpolation methods. This was done to assess which method was more effective for calculating the radionuclide concentrations (actual vs predicted values) in the Berg River area. The results showed that both methods experienced problems to predict unknown values. However, IDW consistently performed better than KDE across most of the interpolation tests. Natural radionuclides are useful predictors to track sedimentation and the results of this paper can serve as a benchmark for future work in tidal and non-tidal coastal environments.

**Keywords:** radiometric mapping, IDW, interpolation, radionuclides, Berg River, QGIS, uranium, thorium, potassium

## 1. Introduction

There is a void in the literature discussing radiometric mapping utilizing free and open-source GIS (FOSSGIS), notably QGIS, according to Henrico et al. (2023). Using the Kernel Density Estimation (KDE) approach, their research graphically represented the distribution of naturally occurring radionuclides of potassium ( $K^{40}$ ), uranium ( $U^{238}$ ), and thorium ( $Th^{232}$ ) in the sediment of the Berg River estuary near Veldrif, South Africa. The authors emphasized the value of FOSSGIS software for sharing knowledge and capacity building and noted that QGIS is a simple to use and free software that is becoming more and more popular for a variety of geospatial analysis tasks, including the analysis and visualization of radionuclides.

The analysis of natural radionuclide concentrations and sediment transport is important for coastal engineering, the protection of the habitat for fish, birds, and other organisms, and the safeguarding of water resources (Rosenmann, 2020; USGS, 2022). Natural radionuclides

have been proposed by Bezuidenhout (2021) as an alternative to synthetic tracers for analyzing sediment transport. This is typically performed through gamma-ray spectroscopy, which detects the elements in the sediment based on the gamma-ray energy released by the individual radionuclides. Processes of sediment movement can be shown by temporal observations taken over the same area. According to Rodrigues, Moatar, and Claude (2011), Earth scientists frequently investigate sediment movement because of their desire to find solutions to ecological issues including "coastal erosion and reservoir siltation". Additionally, the constant exposure to background radiation from sediments and other sources that individuals experience in their natural environment might be harmful (Rodrigues et al., 2011).

Henrico et al. (2023) suggested using QGIS in their earlier work to assist in modeling sediment movement to swiftly analyze radioactive amounts in sediments that could be detrimental to humans and the environment. More significantly, the prior work demonstrated the geospatial method by utilizing QGIS to produce

radiometric maps and KDE. To represent natural radionuclide concentrations, the present study employed the same data and a comparable design but opted to apply the Inverse Distance Weighted (IDW) interpolation method in QGIS. In contrast to the maps made in this work using the IDW approach, the radiometric maps made in the prior study using the KDE technique seemed visually more appealing. However, IDW is an exact interpolator and the radiometric maps highlighted clusters of radionuclide concentrations which provides a visually more accurate and focused display of the radionuclide activities. The statistical analysis conducted in this study confirmed the superiority of the IDW method compared to KDE.

## 2. Methodology

### 2.1 Study area

The research was conducted on a 6 km region starting at the mouth of the Berg River in the town of Velddrif (Figure 1), South Africa, which is approximately 130 kilometers to the north-northwest of Cape Town. The river, one of the largest in the Western Cape, and the estuary were chosen for the research because they were only recently (2 February 2022) "declared a Ramsar Site under the Convention on Wetlands of International Importance."



Figure 1. An image of the study area indicating the Carinus bridge (A) and the Berg River mouth (B) at Velddrif on the West Coast of South Africa

In addition to supporting some of the biggest concentrations of migrating shorebirds in the nation, the estuary serves as an important home for a number of other creatures, including a diverse range of invertebrates (SA-Venues.com, 2023). The Berg River estuary was chosen as a conservation priority, but it also has significant economic significance to nearby communities in terms of commercial fishing, recreation, and salt work and manufacture.

### 2.2 In-situ data collection using DUGS

In situ measurements were performed using an in-house developed system called the Delta Underwater Gamma System (DUGS), which is described in detail, tested, and analyzed in the studies by Kilel et al. (2023) and

Bezuidenhout et al. (2023). In these studies, the detector was dragged behind a boat using a chain along the 6 km stretch starting at the Carinus bridge leading into Velddrif and heading down to the Berg River mouth. The sides and center of the river area were covered by three tracks. Measurements were captured at five (5) second intervals which were geotagged to produce a comma-separated text file. Each sample point contained the spatial locations and gamma-ray count rates of the radionuclides. Post-processing of the measurements included the conversion to activity concentrations using standard calibration methods as described by Bezuidenhout (2015).

The system's components are contained in a waterproof stainless-steel enclosure attached to a delta-shaped stabilization wing. A NaI(Tl) crystal, multichannel analyzer, and TB-5 Digital Tube Base from Amptek® make up the scintillation detector within the enclosure (Figure 2). Custom-developed analysis software running on a laptop computer or rugged tablet such as a Trimble® Yuma 2 featuring an integrated on-board GPS, controls the system.

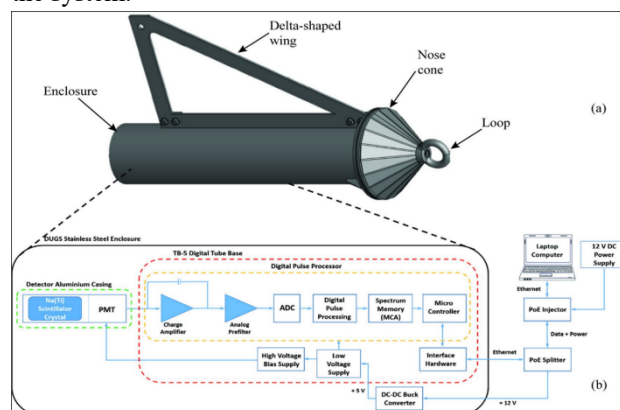


Figure 2. An isometric picture of the enclosure displaying the delta-shaped wing enclosure (a) and the DUGS architecture (b) (Kilel et al., 2023)

### 2.3 Preparing the data for geospatial analysis

The in-situ data measurements are recorded in a comma-separated values (CSV) file. Spatial data saved as a delimited text file can easily be added into a GIS environment with limited data preparation. Most GIS software has tools to quickly import an Excel table into geographic data. In QGIS, this function is performed by using the Spreadsheet Layers plugin (Figure 3).

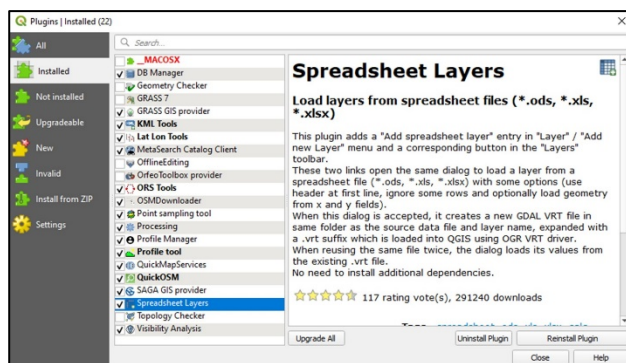


Figure 3. A screen capture of the installed Spreadsheet Layers plugin available in QGIS

Before importing spatial data into a GIS environment, it is advisable to first ensure that it is correct which might entail the process of editing and preparing the Excel spreadsheet data to ensure that the XY data is added to the GIS software. Consistency of the data entries is key. Ensure that there is a good understanding of the data in the spreadsheet and that the columns have meaningful headings, especially the XY data that should be marked with the names 'latitude or Y\_field' and 'longitude or X\_field' for easy recognition. Avoid spaces and special characters as column names. In addition, all spreadsheet entries should be checked for missing values, which should be provided or removed. The data value type (e.g., integer, double, and string) and character total should be correctly set. Esri, on their website, provides good guidelines for working with Microsoft Excel files and formatting Excel tables (Esri, 2018; Rupp, 2023).

In this study, the CSV file that contained the in-situ data measurements was converted to a Microsoft Excel spreadsheet. Since the activity measurements were recorded for three radionuclides, i.e., potassium ( $K^{40}$ ), thorium ( $Th^{232}$ ), and uranium ( $U^{238}$ ), the Excel spreadsheet was partitioned into separate lists, for each of the radioelements. This process ensured that each element could be imported as a separate vector point layer in the GIS environment (Figure 4).

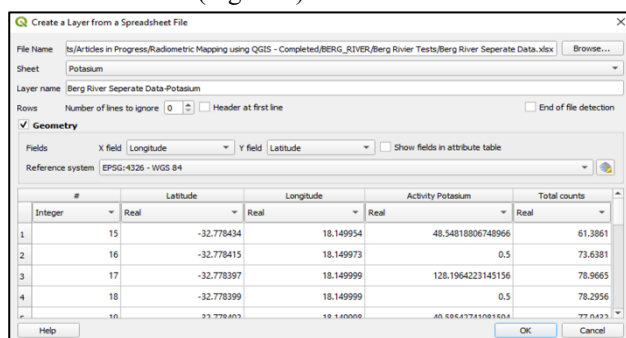


Figure 4. The 'Create a Layer from a Spreadsheet File' dialog box activates when data is added using the Spreadsheet Layer plugin tool

An important aspect of spatial analysis is that the geospatial data need to be projected (Esri, 2020; QGIS, 2022). The 'Create a Layer from a Spreadsheet File'

dialog box consists of an option to define the reference system of the data to be imported. However, the authors found that sometimes the geospatial data is corrupted when this option is set to a projected coordinate system (e.g., UTM) instead of a geographic coordinate system (e.g., WGS84). It is advised to import the geospatial data using the WGS84 referencing system and then to project the data to the relevant projection (location-specific) in the QGIS environment using the Reproject Layer tool. In this study, the geospatial data was reprojected to the WGS 84 / UTM zone 34S (EPSG:32734) coordinate system.

It is necessary to examine and clean the data of any topological flaws, such as duplicates, outliers, under- and overshoots, and dangles, before doing any geographic data analysis (D. Li et al., 2015). There were several clusters and duplicated measurement points in the geographic data that were used in this study. Therefore, each of the data layers (potassium, thorium, and uranium) was cleaned (Figure 5) to ensure precision and accuracy in the interpolation method used and the data analysis that was carried out.



Figure 5. Data cleaning is an important step before geospatial data analysis is conducted

## 2.4 Interpolation method applied for geospatial analysis

To estimate unknown values at unknown locations, a continuous surface model was created using interpolation techniques (Srivastava et al., 2019). Since all interpolation techniques depend on spatial and temporal components, there is no single optimum interpolation technique. A lot depends on the phenomena being monitored and the data collection techniques when choosing a better or preferred interpolation approach. Because of this, interpolation techniques are often site- and data-specific (Childs, 2004; Erdoğan, 2010).

In the earlier work by Henrico et al. (2023), the authors used heatmaps to graphically represent the natural radionuclide concentrations in the Berg River area by using the kernel density estimation (KDE) approach. Data were extrapolated using kernel density estimation to provide an estimated population probability density function. To generate a probability surface, this method applied kernels (weighting functions) to all sample points depending on the effect of nearby points (Glen, 2023; Shi et al., 2019). Henrico et al. (2023) used a 100 m search radius to compute the densities of the radionuclide concentrations in their investigation and used the quartic function to analyze the activity measurements of each element rather than the quantity. The heatmaps created in



the earlier study had a smooth, attractive appearance and displayed clusters of radioactive concentrations to make it simple to distinguish between hot and cool locations of radionuclide concentrations (Figure 6).

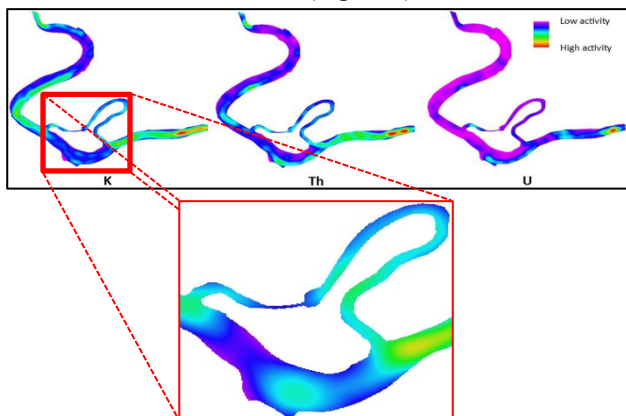


Figure 6. An illustration of the heatmaps to easily identify the clusters of radionuclide concentrations in the Berg River area. The inset image shows the smoothing effect of applying the KDE technique (adapted from Henrico et al. (2023)).

The inverse distance weighted (IDW) interpolation approach is suggested in this study as an alternative to the KDE to graphically depict naturally existing radionuclides in the Berg River estuary. IDW is a nonstatistical interpolation technique that uses a straightforward, deterministic approach to forecast the surface of unknown values (J Li, 2013; Wang et al., 2014). The IDW technique enforces the requirement that nearby known points are more likely to have an impact on a point's estimated value than are points further away. IDW was chosen for this study because it is an exact interpolator (Lynch, 2008), and the surface maps created smaller clusters of the radioactive concentrations (Figure 7), which is a more accurate and precise representation to analyze radionuclide concentrations in sediments at specific areas.

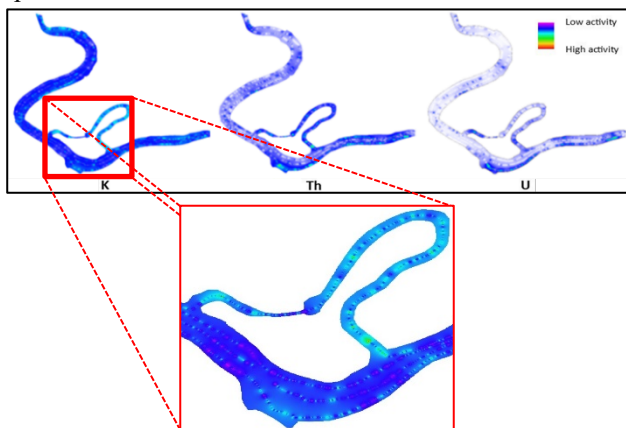


Figure 7. Side-by-side illustration of potassium (K), thorium (Th), and uranium (U) concentrations in the Berg River. The inset image shows the exactness of the IDW interpolation method.

In the next section, the radiometric maps produced by applying the IDW interpolation method are briefly presented. In addition, the results and performance of the IDW and KDE interpolation methods are statistically analyzed by conducting a linear regression analysis.

### 3. Presentation and discussion of results

#### 3.1 Radiometric maps created by applying the IDW interpolation method

In the previous study by Henrico et al. (2023), the authors created radiometric maps for each element using the KDE technique available in QGIS. The present study used the same data and a similar design but created the radiometric maps using the IDW method to display the radionuclide concentrations. Consequently, the analysis of the results indicated by these maps falls outside the scope of this paper; instead, a visual comparison between the IDW and KDE approaches is presented. In comparison to the KDE methodology, the visual examination supports the accuracy of the IDW method (see Figures 6 and 7). Additionally, a straightforward linear regression analysis function offered by QGIS was used to analyze the accuracy of the IDW and KDE approaches.

Figure 8 shows the radiometric map for the concentrations of potassium (K) that was created using the IDW method. Radiometric maps were created for each of the radionuclide concentrations and Figure 8 was only included as an example of these maps using the IDW interpolation method.

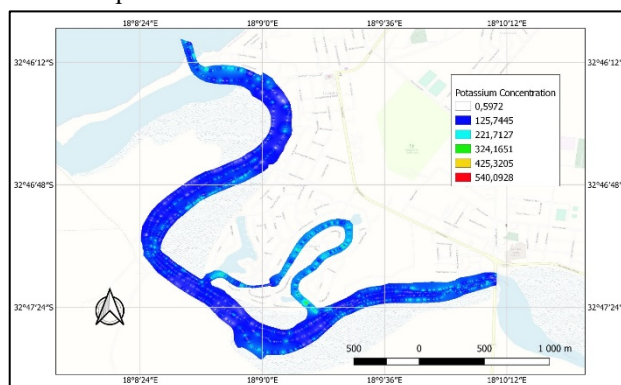


Figure 8. Radiometric map indicating the concentrations of potassium (K)

In addition to the three radiometric maps created in QGIS, a ternary map (Figure 9) was also generated by merging the three composite radiometric maps for potassium (K), thorium (Th), and uranium (U). The ternary map provided valuable spatial correlations between the elements and demonstrated the effectiveness of the ternary map for sediment studies. The predominant element concentrations per location in the study area are easily recognizable in Figure 9. This is a characteristic of the IDW exactness.

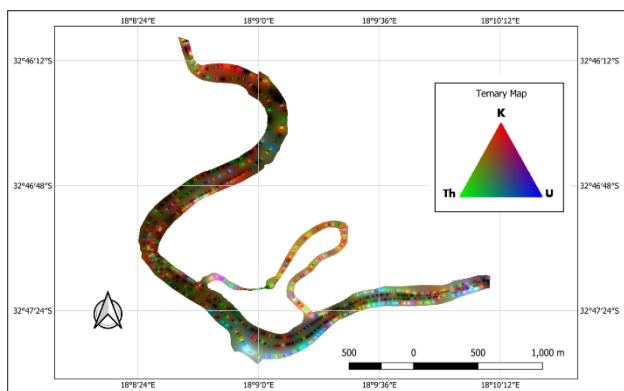


Figure 9. Ternary map showing a colour composition red = K (potassium), green = Th (thorium) and blue = U (uranium)

### 3.2 Statistical analysis of the interpolation method

The statistical analysis comprised of linear regression analysis with a static model fit ( $R^2$ ) performed in the IBM SPSS Statistics (version 29) statistical analysis software. The comparison criteria between the two interpolation methods were based on the statistical relationship between the actual ( $Y$  – dependent variable) and estimated ( $X$  – independent variable) values of the radionuclide activities. The statistical analysis indicates the normal P-P plot of the regression standardized residual, the model summary for each test, the ANOVA test results, the coefficients, and the residual statistics.

The probability-probability (P-P) plots for both the IDW and KDE interpolation methods (for each radionuclide element) are indicated in Figure 10. P-P plots are typically used to assess if the data are distributed according to a certain pattern (such as the normal distribution). A roughly straight line connecting the data points indicates that the data closely match the presumptive distribution.

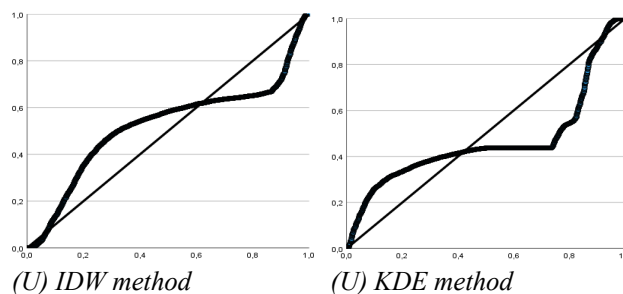
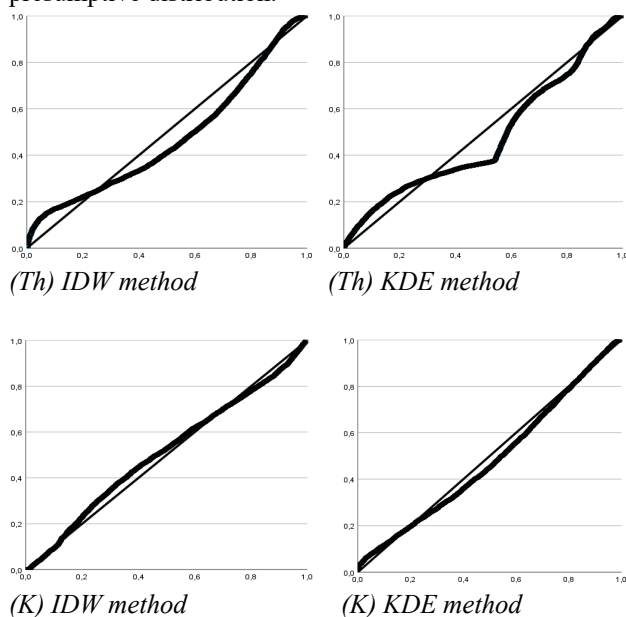


Figure 10. Probability-probability (P-P) plots indicate the distribution patterns of the actual values against the predicted values. The X-axis represents the observed probability and the Y-axis the expected probability.

In addition to the individual plots indicated in Figure 10, which provide a side-to-side comparison of each interpolation method, P-P plots (Figure 11) were also calculated for all observed and predicted values for each method. The S-shaped curve for both models indicates that the distribution of residuals is skewed. Both methods therefore experienced problems to make predictions. However, the IDW method in all the cases matches the presumptive distribution more closely than the KDE method.

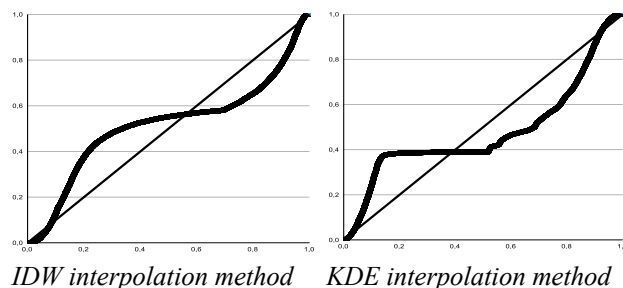


Figure 11. Probability-probability (P-P) plots indicate the distribution patterns of all the actual values against predicted values for both the IDW and KDE methods. The X-axis represents the observed probability and the Y-axis the expected probability.

The regression model descriptive statistics for all values (observed vs predicted) between the IDW and KDE interpolation methods are indicated in the tables below (Table 1 – 3). Table 1 indicates the model fit by displaying the 'goodness-of-fit statistics'. The Analysis-of-Variance (ANOVA) is also indicated in the table. The linear regression model showed a good fit to the data, with an  $R^2$  of 0.943 ( $p < 0.001$ ) for IDW and 0.589 ( $p < 0.001$ ) for KDE. The ANOVA showed great separation between the actual and predicted values for both interpolation methods ( $F = 177565,016$ ,  $p < 0.001$  for IDW, and  $F = 14935,264$ ,  $p < 0.001$  for KDE). However, generally, the results indicate that the IDW method is a better-fit method than KDE to predict unknown values, which is also confirmed by the statistics presented in Tables 2 and 3.

Table 1: Regression model summary for both IDW and KDE interpolation methods

Method	R	R <sup>2</sup>	Adjusted R <sup>2</sup>	Std. The error in the Estimate	ANOVA Change Statistics		
					R <sup>2</sup> Change	F Change	Sig. F Change
IDW	.971*	.943	.943	18.550140029	.943	177565.016	<.001
KDE	.768*	.589	.589	50.112673872	.589	14935.264	<.001

The regression coefficient B in Table 2 indicates for the IDW method that while the actual value (Y) decreased, the predicted value (X) increased. The table also indicates that the opposite is true for the KDE method, while the actual value (Y) increased, the predicted value (X) also increased.

Table 2: Regression coefficients

Method		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
IDW	(Constant)	-3.913	.224		-17.485	<.001
	X_Predicted_IDW	1.074	.003	.971	421.385	<.001
KDE	(Constant)	14.562	.592		24.610	<.001
	X_Predicted_KDE	.010	.000	.768	122.210	<.001

The residuals of the linear regression model had a mean of 0.000 (SD = 18.549) for the IDW method and 0.000 (SD = 50.11) for the KDE method. In both, the mean is close to zero, which suggests that the predictions of both models are not significantly biased. However, the standard deviation in both cases is large which suggests potential biases in the predictions of both models.

Table 3: Residual statistics

Method	Coefficients	Minimum	Maximum	Mean	Std. Deviation	N
IDW	Predicted Value	-3.33086	495.14370	52.99292	75.199250	10806
	Residual	-130.471649	126.078575	.000000	18.549281	10806
	Std. Predicted Value	-.749	5.880	.000	1.000	10806
	Std. Residual	-7.033	6.797	.000	1.000	10806
KDE	Predicted Value	14.56158	239.34745	54.89687	60.018750	10413
	Residual	-211.458572	449.558746	.000000	50.110267	10413
	Std. Predicted Value	-.672	3.073	.000	1.000	10413
	Std. Residual	-4.220	8.971	.000	1.000	10413

#### 4. Conclusion

According to the definition of deltas by Galloway (1975), the Berg River estuary is a tidal delta characterized by sandstone and shale, which include naturally occurring radionuclides ( $K^{40}$ ,  $U^{238}$ , and  $Th^{232}$ ) (Bezuidenhout, 2021; Bugan, Jovanovic, & De Clercq, 2012). Predicting the range of these concentrations, which might carry dangers to human health and the environment, is crucial. In this work, the IDW interpolation method is suggested as an alternative to the KDE method, which Henrico et al. (2023) utilized in a prior study to build radiometric maps.

It is clear from looking at Figures 6 and 7 that the KDE technique generated a smoother display of the interpolated surface compared to the rougher surface of the IDW method. This is explained by the fact that the IDW approach is an exact interpolator while the KDE method is regarded as non-exact. Non-exact interpolation techniques do not always travel over all of the provided data points, and as a result, a smoothing approximation of the data is created that is not always a true representation

of the original data. In contrast, exact interpolation techniques guarantee that the interpolated values accurately travel across all the provided data points and truly replicate the original data.

This research demonstrated the effectiveness of IDW over KDE for producing radiometric maps of the Berg River. To examine the reliability of both interpolation techniques, a linear regression analysis in SPSS was conducted. The findings indicated that both techniques had trouble predicting unknown values. However, in most of the interpolation tests, IDW consistently outperformed KDE.

Any interpolation method's accuracy prediction is influenced by several variables, such as data accuracy, density, distribution, terrain type, and the spatial resolution of the output grids (J. Li & Heap, 2011). There are many interpolation techniques, but their effectiveness is typically only shown in real-world applications. As a result of the exact display of projected values in this study, the IDW approach was suggested. These findings suggest that future research should concentrate on evaluating other interpolation techniques, such as Kriging, a geostatistical interpolator. This will provide additional verification of the performance of different interpolation techniques to create radiometric maps.

#### 5. Acknowledgement

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