SPATIAL CONCENTRATION OF CESIUM(CS-137) AT THE CHERNOBYL EXCLUSION ZONE

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I. INTRODUCTION

1) PROBLEM STATEMENT:

TO STUDY THE DISTRIBUTION AND SPATIAL CONCENTRATION OF CESIUM 137 AT THE CHERNOBYL EXCLUSION ZONE.

2) OBJECTIVE:

- The Major Objective Of This Project Is To Study The Spatial Concentration Of Cesium (Cs - 137) At The Chernobyl Exclusion Zone.
- The Extent And Concentration Of Spread.
- Identifying The Hotspots Of Radiation Around The Reactor.

3) SIGNIFICANCE:

Energy Consumption Plays A Significant Role In Development. The Traditional Sources Of Energy Includes Coal Based Power Station, Fossil Fuel Based Electric Power Station. The Major Issue With These Sources Of Energy Is That They Have Very Bad Environmental Impact.

Many Of The Traditional Sources Of Energy Being Non – Renewable Are Not Going To Be Available In The Future. With These Problems That Plagues Us We Are Moving Towards Other Forms Of Energy Like Solar Energy, Wind And Geo-Thermal Energy.

These Sources Of Energy Have Minimal Environmental Impact But They Are Plagued With Other Problems Like Un-Reliability. These Energy Sources Are Dependent On Major Environmental Factors Like Weather, Geographical Location, Environment And So On.

With These Factors In Mind One Of The Most Promising Sources Of Energy Is Nuclear Power. There Are About 440 Nuclear Power Stations Across 30 Countries And With The Demand Increasing, We Are Expecting There Is Going To Be A 4 Fold Increase In Its Number In The Next 50 Years.

The Nuclear Power Although Promising Has Serious Environmental Impacts In That If Its Not Handled Properly Or An Environmental Impact Like Earth Quakes Or Tsunami Could Potentially Result In Catastrophe.

We Have Witnessed It At Chernobyl, Fukushima Daichi Being The Most Major Contributor Of Nuclear Disasters In Terms Of Scale.

The Chernobyl Nuclear Disaster Occurred On 26Th April 1986 At Reactor Number 4 At The Chernobyl Nuclear Power Station Near The City Of Pripyat In The Northern Parts Of The Ukrainian Socialist Soviet Republic.

We Wish To Study The Extent And The Concentration Of Cesium That Was Released During The Nuclear Explosion.

The Wind, Rainfall And The Various Other Natural And Artificial Factors Like Animals Have Played An Important Role In The Dissipation Of These Elements.

By Analyzing The Data On The Spread Of These Elements We Can Analyze The Spread Of The Radio Isotope And Also Analyze The Radio Activity In These Regions.

This Analysis Helps Us Understand If These Regions Are Safe For Rehabilitation As The Exclusion Zone Spans 2600 Sq Kms In Terms Of Area Which Is A Very Huge Area That Was Needed To Be Evacuated.

II. Literature Review

II.I ORDINARY KRIGING (METHOD USED)

Ordinary Kriging Is Most Used Geo Spatial Analysis Tool:

Let Us Suppose That There Is A Random Field Z(X) Represented By Set Of Given Values $Z(X_i)$ Measured At Locations X_i. According To Linear Estimator The Value At An Unmeasured Location $X_0(Z^*(X_0))$ Is Given By The Following Equation:

$$Z^*(X_0) = \sum_{i=1}^{N(X_0)} \lambda_i Z(X_i) \quad (1)$$

Where N(X_0) Is The Number Of Samples Of The Neighborhood X_0 Taken Into Account For The Estimation And λ_i Are Ordinary Kriging Weights. The Neighborhood Depends On A User Defined Search Rule. It Can Be Defined As A Circle With A Search Radius Or As A Ellipse With Major And Minor Axis Orientation. The Neighborhood Is Expected To Be Small Enough To Preserve A Limitation On The Constant Mean. For Meaningful Estimation The Neighborhood Must Contain At least 3 Samples.

The Set Of Weights (λ) Is Determined By Minimizing The Estimation Of Variance Under The Constraint Of Unbiasedness:

$$min_\lambda Var((Z^*(X_0;\lambda) - Z(X_0)) - \mu(\sum_{i=1}^{N(X_0)} \lambda_i)) \quad (2)$$

By Solving The Ordinary Kriging Equations:

$$\begin{cases} \sum_{i=1}^{N(X_0)} \lambda_i \gamma_i - \mu = \gamma_{j0}, \qquad j = 1, \dots N(X_0) \\ \sum_{i=1}^{N(X_0)} \lambda_i = 1 \end{cases} \tag{3}$$

Where μ Is The Lagrangian Multiplier. It Is A Linear System Of $N(X_0) + 1$ Equations With $N(X_0) + 1$ Unknowns. γ_{ij} Corresponds To A Spatial Correlation Structure Of Random Field Described By A Semi Variogram:

$$\gamma_{ij} = \gamma(h_{ij}) = \frac{1}{2} Var(Z(x + h_{ij}) - Z(x)) \tag{4}$$

Where h_{ij} Is A Vector Separating Locations X_i And X_j. The Ordinary Kriging Equations Have Unique Solutions If They Are Well Defined (NOT SINGULAR). The Kriging Estimation Error Is Described By The Kriging Variance

$$\sigma^2 = \sum_{i=1}^{N(X_0)} \lambda_i \gamma_i + \mu \tag{5}$$

Directly Estimated Once Kriging Equation (3) Is Solved. Under Assumption Of A Local Gaussian Distribution A 95% Confidence Interval Around Kriging Estimate Is $[Z^* (X_0) - 2\sigma;\ Z^* (X_0) + 2\sigma]$

To Use Ordinary Kriging It Is Necessary To Define Search Rule And Semi Variogram Values For All Possible Separating Vectors. The Parameters Are Decided From The Raw Data That Is Available.

II.II Related Works

1) **AUTOMATIC REAL-TIME INTERPOLATION OF RADIATION HAZARDS: PROTOTYPE AND SYSTEM ARCHITECTURE CONSIDERATIONS [Paul H. Hiemstra , Edzer J. Pebesma , Chris J.W. Twenhöfel , Gerard B.M. Heuvelink]**

Kriging Is One Of The Most Commonly Used Interpolation Technique In Spatial Statistics. Detection And Monitoring Of Radio Active Releases In Atmosphere Is Important. The Netherlands National Radio Activity Monitoring Station Uses Monitoring Stations All Across Netherlands To Collect The Data On Background Radiation And Monitors The Data At The Interval Of Every 10 Minutes. This Data Is Then Interpolated Using Kriging And Is Then Compared To The Historical Data To Analyze The Patterns Of Radiation.

Its Observed That The Radiation Levels Depends On The Type Of Soil And Not All Soils Have The Same Type Of Background Radiation. By Analyzing This Data At Constant Intervals Across A Reasonably Large Span Of Time We Can Estimate The Inherent Background Radiation In That

Given Area. This Data Can Be Used To Estimate The Increase In The Radiation Incase Of Natural Or Man-Made Disasters And Monitor The Overall Radio Activity Across The Region.

The Maps Generated Using Interpolation Have 95 Percent Prediction Accuracy And The Intervals Are Automatically Monitored If The Thresholds Are Exceeded Or Not. The Radio Activity Is Not Static But An Extremely Dynamic Process Where We Observe That The Radio Activity Shortly Increases In Bursts In Case Of Rainfall At Certain Regions.

Its Observed That The Radio Activity Increases Due To The Wet Deposit Of Radon Progeny Incase Of Heavy Rainfall Which Is A Short Lived Radio Source. The Natural Sources Like Meteoroids, Solar Emissions Can Also Cause The Atmospheric Compositions To Change Drastically. By 0bserving And Also Studying The Underlying Cause Helps Us Detect Subtle Changes In The Emission Rates And This Will Be Useful In Real Time Prediction Of Disaster.

The Monitoring Although Real Time Is Not Very Efficient Due To The Lack Of Appropriate Ground Stations But The Data That Is Produced By Interpolating The Data Covers The Lacunae And Can Monitor The Region With Fair Accuracy. This Data Can Be Used To Generate An Appropriate Response. The Activity Is Generated In Form Of A Raster.

It Was Observed That Kriging Gave Much Better Result In Comparison Of Other Deterministic Methods Like Inverse Distance Interpolation. The Advantage That Was Observed Over These Methods Was Its Ability To Quantify Interpolation And Include Trends Such As Precipitation And Soil Type To Interpolation.

2) MAPPING RADIOACTIVITY FROM MONITORING DATA AUTOMATING THE CLASSICAL GEOSTATISTICAL APPROACH [Edzer J. Pebesma]

The Most Efficient Way To Monitor Radio Activity Details Is Through Automation. The Constant Monitoring Task Is Tedious And When The Operator Has To Take A Look At The Same Location For Changes For A Long Time They Might End Up Missing Important Changes Due To Fatigue. To Overcome This Challenge, We Look At Ways To Automate This Monitoring Process. The Author Discusses On Using Classical Geo-Statistical Models To Automate The Mapping Of Background Radiation Using Kriging And Co-Kriging.

The Models Needs To Make The Decision Based On 1) Outlier Detection, 2) Choice Of Isotropic Variogram Model, 3) Choice Of Variogram Cutoff Distance And Lag – Width, 4) Verification Of Directional Dependency, 5) Verification If Co-Kriging Improved The Prediction, 6) Optimization Of Kriging Neighborhood.

The Intricacy Involved In Modelling Such A System Are Many As We Observe That In Certain Cases The Co-Kriging Did Not Improve Prediction In Cross Validation Settings. The Possible Reason For It Is Attributed To Isotropy. All The Data In Consideration Have The Same Location Of Collection And So The Variography Might Be Close To Intrinsic Correlation Model And Co-Kriging Is Similar To Ordinary Kriging. Also Fitting A Linear Model Of Coregionalization Imposes Strict Limits To Variogram Range Parameter.

The Isotropic Co-Kriging Can Only Improve Over Kriging If Secondary Variable Is Much More Closely Correlated Than Primary Variable. Due To The Constant Tweaking Of Parameters Required In Kriging And Co-Kriging In Case Of Changes In The Data The Models Fail Continuously. Like In case Of Anomalies Like A Sudden Increase\ Decrease Due To Natural Or Man Made Causes.

Robust Frame Work Needs To Be Created Incase Of Detection Of Anomalies Automatically And Only By Using The Algorithm Cannot Guarantee Results. They Need To Be Supplemented With Smart Parameter Tweaking Mechanisms.

The Valuable Lesson That Could Be Inferred Was That Although The Automated Kriging Variogram Model Was Able To Sufficiently Predict The Results In Case Of Ordinary Data Its Unable To Predict Incase Of Data That Is Not Normal Or Contains Anomaly So A Threshold Could Be Set Incase An Anomaly Is Detected Beyond A Certain Threshold Then We Need To Automatically Start Tweaking With The Subtle Model Parameters Like The Search Neighborhood To Heavy Changes Like The Change In The Model Used Like Exponential, Gaussian,…etc.

3) IDENTIFYING ANOMALOUS NUCLEAR RADIOACTIVE SOURCES USING POISSON KRIGING AND MOBILE SENSOR NETWORKS [Jifu Zhao, Zhe Zhang, Clair J. Sullivan]

Poisson Kriging Is A Novel Approach Towards Detection Of Radiation. The Paper Discusses On The Usage Of Mobile Phones To Get The Accurate Location Of The Readings Combined With The Geo Spatial Data Of The Area To Get An Estimate Of The Amount Of Radiation In That Region. This Data Is Then Interpolated Using Poisson Kriging To Get An Accurate Estimate On The Radiation In That Region.

The Poisson Kriging Is Different From Ordinary Kriging In The Way That It Assumes That The Data Follows Poisson Distribution Which Is Good Estimation In Case Of Sudden Anomalous Data. By Using Poisson Kriging We Can Have A Much Better Estimate Incase Of Data That Does Not Follow A Normal Distribution.

In Poisson Kriging We Calculate The Covariance Between The Points Of Interest And This Helps Us To Accurately Predict The Distribution Accurately. The Potential Downside Of This Model Is That The Points Need To Be Close To One Another And The Estimate Accuracy Decreases As The Distance Between The Points Increases As The Model Cannot Scale The Estimates Accurately.

The Reason Behind It Is Because As The Distance Between The Points Decreases The Correlation Increases And As The Distance Increases The Correlation Between The Points Decreases And We Potentially Reach A Stage Where There Is No Correlation Between The Points

Eg:- In This Paper The Model Yielded Good Results When The Points Were 5 Meters Away From One Another But Was Yielding Poor Results When We Try And Estimate The Values When Points Is Placed At A Distance Greater Than 10 Meters

Due To This Unique Challenge Faced Although The Poisson Kriging Would Not Be A Good Estimate For Modelling The Radio Active Monitoring In Large Scale Applications As The Data Would Not Scale Efficiently.

With The Distance Between Points That Are Located Very Far Away From One Another Covering A Large Region Poisson Kriging Is Highly In-Efficient. In A Mobile Detection Setup Its Very Accurate As The Distance Between Points Is Extremely Small Rendering The Correlation Between The Points To Be Extremely Large.

4) **USING ORDINARY KRIGING TO MODEL RADIOACTIVE CONTAMINATION DATA [Elena Saveliena]**

One Of The Most Commonly Used Algorithms In Geo-Statistics Kriging Is Used To Model The Data. Its Observed That When Applied To Data That Had Normal Distribution, It Gave Us Excellent Results. But When This Method Is Applied To A Data Set Containing Outliers The Results Are Not Optimal.

As A Phenomenon It Was Observed That When Applied To Joker Dataset The Results Were Sub-Optimal. It Was Observed That The Experimental Semi Variogram Observed Very Short Correlation Ranges – More Than Two Times Shorter Than The One For Routine Prior Data. There Is No Real Correlation Between The Flux Values And The Parts Of The Region Not Yet Affected By The Flux.

Since The Theoretical Limits Of Ordinary Kriging Are Violated In The Region Around The Flux, The Estimation Of The Region Around The Flux Becomes Biased (Strongly Under-Estimated). The Unaffected Parts Of The Regions Are Predicted Well By The Ordinary Kriging With The Pre-Selected Parameters They Display Pattern Similar To The Prior Data. The Flux Regions Are Detected Well Despite The Strong Smoothening Effects. The Applications Of Irrelevant Semi Variogram Model Certainly Brings Some Negative Consequences, But Still The Ordinary Kriging Estimates Are Not Meaningless.

The Following Observations Can Be Concluded From This Paper: The Model For Spatial Correlation Structure Can Be Built And Used If There Is Temporal Persistence In The Data. Otherwise, A Different Model Needs To Be Built To Fit The Data Incase An Anomaly Is Detected. i.e., Incase Of Emergency A Different Model Needs To Be Built. We Can Infer This Assumption From The Results When The Model Was Used To Model The Data Joker.

Ordinary Kriging Using Semi Variogram Model Fitted To Prior Data Provides Good Results For Routine Cases And Also For Some Cases Incase Of Emergency Results. Being A Fast And Simple

Method, Ordinary Kriging Can Be Applied And Incorporated Into A Decision Support System With Semi-Automatic Semi Variogram Tuning.

5) STUDY ON APPLICATION OF KRIGING TO EVALUATION OF RADIOACTIVITY CONCENTRATION FOR ENSURING COMPLIANCE WITH THE CRITERION OF SITE RELEASE [Tsutomu Ishigami, Taro Shimada]

After A Nuclear Power Plant Ceases Operation Permanently The Plant Is Dismantled And The Nuclear Site Is Eventually Released From Regulatory Control In US. Due To Fukushima Daichi Accident There Are A Large Number Of Nuclear Power Plants Which Are In Dismantling Stage.

The Author Applies Kriging To Evaluate The Mean Radio Activity For The Determination Of Radio Activity Concentration. For This We Apply Mean Kriging Which Estimates The Mean Value Of The Physical Quantity On A Wider Area Basis. We Are Going To Make Two Calculations: MK 1 (Mean Kriging-I), MK 2 (Mean Kriging-II).

In MK-I, The Estimation Variance Of The Difference Between The Estimator Of The Mean And True Mean Is Minimized To Obtain Kriging Solutions.

In MK-II The Estimation Variance Of The Estimator Of The Mean Is Minimized. Variograms Among Only The Measurement Points Are Considered To Estimate The Mean.

The Method Is Applied On JAEA Site Which Is An Area Surrounding The Pu2 Facility and Trojan Nuclear Facility. We Observe That

1. The optimized variogram models determined by the cross validation and optimized method were significantly different from the fitted variogram models in some cases. It is desirable to employ the optimized model in kriging calculations.

2. When the measurement points were not selected uniformly but selected from the region with higher counting rates data (the case of the area surrounding the Pu2 facility), the estimated mean by conventional statistical methods was a higher value.

3. However, the estimated mean by MK-I was reasonable because a spatial correlation between two different points could be considered. On the other hand, MK-II provided larger standard error of the estimated mean than MK-I and conventional statistical methods. This results in decreasing the reliability of the estimated mean.

4. MK-I and conventional statistical methods results showed minimum dependency of minimum number of measurement points on n_0, but MK-II results showed significant dependency. This means that the results by MK-I and conventional statistical methods are more reliable than those by MK-II.

5. When there was little spatial correlation (the case of the survey unit on the Trojan site), MK-I and conventional statistical methods provided similar results of the mean, standard error, and minimum number of measurement points.

6. When there was spatial correlation and further when the measurement points were distributed inhomogeneously (the case of the area surrounding the Pu2 facility), MK-I provided smaller minimum number of measurement points than MK-II and conventional statistical methods. This indicates that MK-I is a more efficient measurement method than MK-II and conventional statistical methods.

6) SPATIAL ANALYSIS OF 137 CESIUM IN THE ENVIRONMENT [G. Dubois, P. Bossew]

We Review The Current Methods Used To Analyze Cesium – 137 Deposit In Europe After The Chernobyl Nuclear Disaster Which Occurred On The Night Of 26th Of April 1986 At The Chernobyl Nuclear Power Station. Following The Explosion There Were Particles Released Due To Combustion Of Nuclear Fuel During The 10 Days Following The Accident. This Release Contaminated The Whole Northern Hemisphere. The Radio Active Elements Were Released In Their Gaseous (Xe-133, Kr-85, I-131,132, Ru-103,106)And Aerosol Forms (Cs-134,137,Sb-125,Sr-90, Pu-238,239,240).

Radio Nucleotides Released During Accidents Are Released And Deposited On Ground Either By Dry Deposition Or By Wet Deposition. First Process Occurs By The Direct Contact Between The Contaminated Surface And Radio Active Chunks. It Is A Continuous Process As Long As There Is Radio Activity In Air, Based On Sedimentation, Absorption And Impacting.

Dry Deposition Is Important For Gasses But Less For Gasses For Which Wet Deposition Seems To Be Main Factor To Be Affecting It. Wet Deposit Is The Interaction Between The Rainfall Fields And Radio Active Clouds.

The Major Methods To Measure Radio Activity Is 1) Soil Samples, 2) In Situ Gamma Spectroscopy, 3) Air Borne Gamma Measurement.

Due To The Chernobyl Accident The Following Pattern Of Deposition Was Observed:

Mean > 80Bq/m^2 Was Estimated To 8270 m^2 And Calculated To Be Equal To 7660 m^2.

Mean > 100kBq/m^2 Was Estimated To 440m^2 And Calculated As 620 m^2

Estimated Data – Derived Through Interpolation.

The Radio Activity Changes Is A Dynamic Phenomenon Which Occurs Regularly And Is Not Static. The Various Environmental Factors As Discussed Above Are Responsible For The Dissipation Of The Radio Active Substances Thereby Temporarily Reducing Or Increasing The Radio Activity In That Given Region.

7) DETECTION AND PARAMETER ESTIMATION OF MULTIPLE RADIOACTIVE SOURCES [Mark Morelande, Branko Ristic, Ajith Gunatilaka]

Given An Area With Unknown Number Of Radio Active Sources Two Methods Are Estimated: Maximum Likelihood Estimation, Generalized Maximum Likelihood Rule. The Second Method Estimates The Parameters And Number Of Sources In Bayesian Frame Work Via Monte Carlo Integration. The Problem Of Radiological Source Estimation Is Considered. Here Both The Source Number And Source Parameter Estimation Problems Were Considered.

First, A Maximum Likelihood Algorithm Was Studied For Estimation Of The Number Of Sources And Their Parameters. This Algorithm Demonstrated Good Performance For A Two Source Scenario But Is Not Feasible For Scenarios Containing Three Or More Sources.

Another Drawback Of The Maximum Likelihood Algorithm Is Its Relatively High Threshold SNR. Both Of These Deficiencies Are Remedied By The Bayesian Estimation Algorithm Proposed Here. Importance Sampling With Progressive Correction Is Used To Approximate The Intractable Integrals Which Arise In The Bayesian Approach. Simualtions Showed That The Bayesian Approach Is Capable Of Excellent Performance in Two And Three Source Scenarios With Reasonable Computational Expense

8) **THIRTY YEARS AFTER THE CHERNOBYL ACCIDENT: WHAT LESSONS HAVE WE LEARNT? [N.A.Beresford,S.Fesenko,A.Konoplev,L.Skuterud,J.T.Smith,G.Voigt]**

Due To The Chernobyl Accident There Was A Large Amounts Of Radio Active Debris Released Into The Atmosphere And Due To Which A Large Area Of Land Was Deemed Un-Suitable. Approximately 2,600 Kms Of Land Is Deemed Unusable For Cultivation And Human Habilitation. We Are Still Analyzing The Long term Effects Of Radiation. As There Was No Data That Was Collected On The Radio Activity In The Initial Stages Of The Accident Due To The Lack Of Knowledge And Suitable Techniques, The Exact Nature Of The Spread Of The Radiation Is A Fine Guess But Is Difficult To Pin-Point To A Large Degree.

But As The Time Has Passed We Have Made A Huge Progress In Calculating The Amount Of Radiation Dissipation Using Various Geo Statistical Modelling Techniques. This Paper Discusses The Methods Of Reducing The Effects Of Radiation In These Areas. Some Of The Methods Include Simple Tilling Of Soil To More Complex Understanding Of Radio Active Compounds And Its Dilution Mechanisms.

It Also Discusses The Method Of Reducing The Radiation Transfer In The Animals That Are Bred In And Around This Areas. The Amount Of Radiation Increases As We Go Up The Food Chain. A Simple Few Micro-Grams Of Radio Active Debris In Plants Could Potentially Be Exponentially Increased In Quantity Inside The Food Chain In Higher Levels Such As Tigers. It Discusses In Detail About The Average Radio Debris In Wild In And Around This Region.

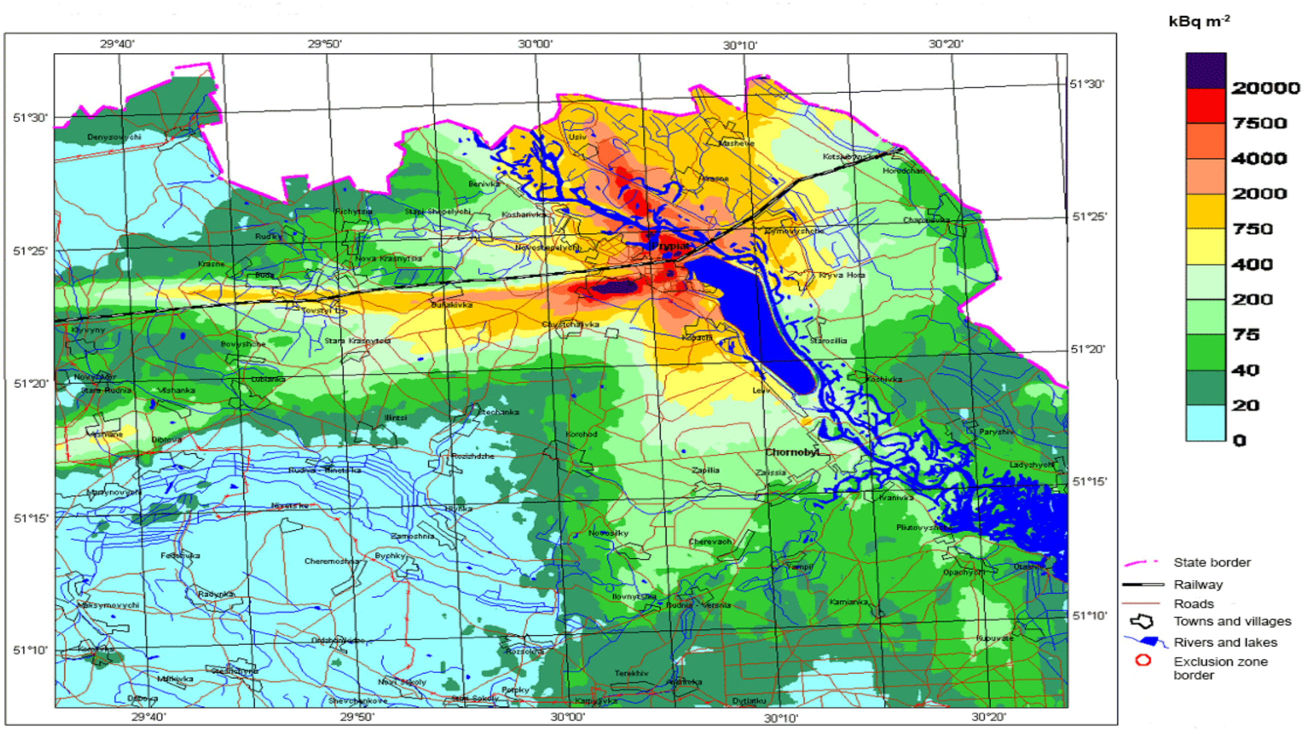
It Also Discusses The Mechanism On How Various Factors Play A Significant Role In The Dissipation Of This Radiation. The Author Also Helps Us Analyze How Radiation Is Transported By Animals From Various Areas And Also On The Accumulation Of Radiation In The Food Chain. We

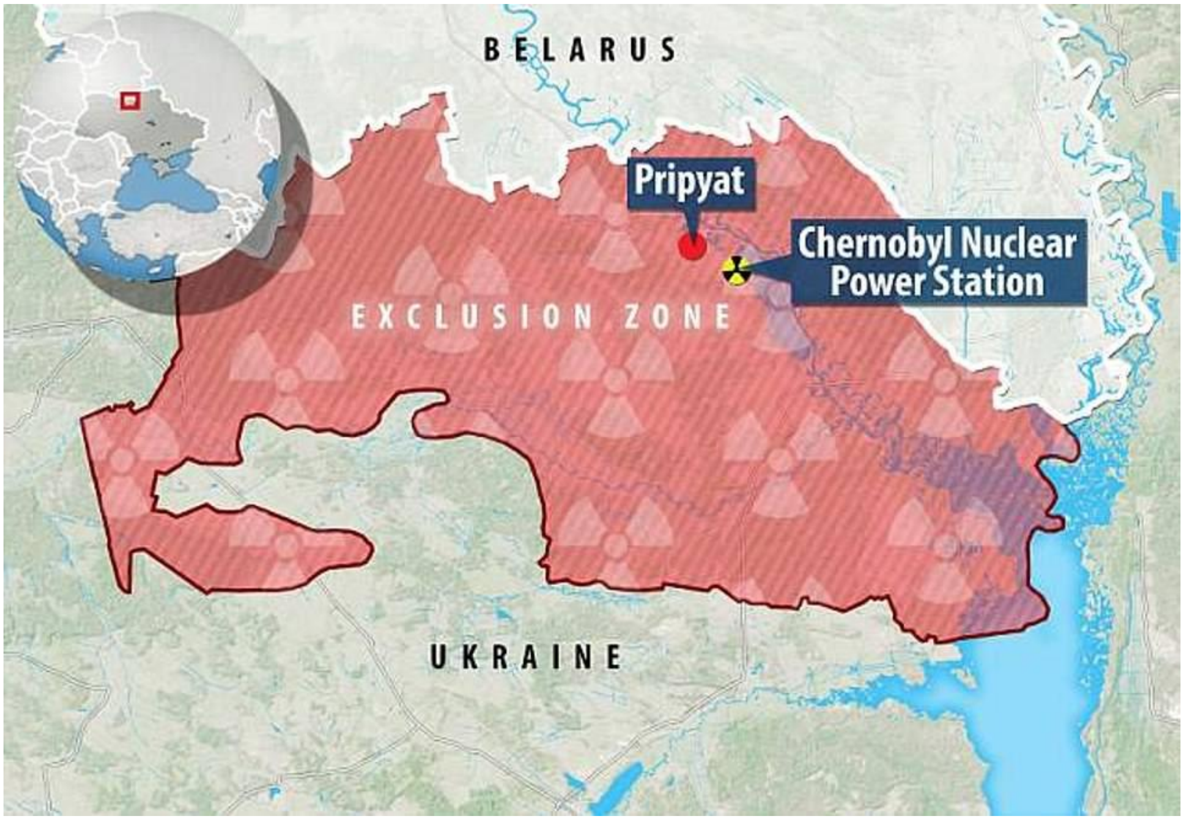
Study The Effects Of Radiation In And Around The Exclusion Zone And Also Study The Effects Of It On Plants And Animals To Understand The Causes, Nature And Spread Of Radiation.

Although It Does Not Have A Huge Technical Significance In The Context Of This Project It Plays An Important Role In Understanding The Reason For The Unequal Dissipation Of Radioactive Debris And Also Helps Us Evaluate The Effects Of Discretely Lower And Higher Amounts Of Radiation In The Region Of Interest Of Our Paper. The Discrete Distribution Of The Cesium In The Chernobyl Exclusion Zone Could Be Attributed To The Factors Discussed In This Paper. By Studying The Factors Discussed Above We Can Evaluate The Spread In The Last 30 Years. This Helps Us Understand The Intricacy Of The Differences Between The Actual Background Radiation And The Radiation That Has Increased Due To The Accident.

III.) STUDY AREA

Starting On 27 April 1987, The Human Population And Farm Animals Were Evacuated From An Area Of Approximately 3500 km^2 To Create What Has Become Known As The Chernobyl Exclusion Zone (CEZ). Subsequently, The Area Administered As The CEZ Has Increased To Approximately 4760 km^2. The Area Of The CEZ In The Ukraine Is Approximately 2598 km^2, With The Remainder Being In Belarus. The Deposition Of Radionuclides Over The CEZ Is Known To Be Highly Spatially Heterogeneous. Releases From The Chernobyl Reactor Occurred Over A Period Of About 10 Days. There Is A Narrow Band Of High RadioActivity To The West Of The Reactor (Often Referred To As The Western Trace) Which Represents Deposition From The Initial Explosion. Higher Levels Of Contamination To The North And To a Lesser Extent To The South Are A Consequence Of Releases Over The Days Following The Accident.**CHERNOBYL EXCLUSION ZONE**





IV.) DATA AND METHODOLOGY

Spatial Dataset Of Radio Cesium Was Collected Through Sampling Exercise Conducted During The Summer Of 1997. The Dataset Comprises Results From 1200 Soil Samples Which Gives Us Reports Of ^{134}Cs, ^{137}Cs, ^{90}Sr And Some ^{154}Eu Activities In Soil (kBq m^{-2}) And Latitude–Longitude Co-ordinates.

Soil Samples Were Collected At About 1200 Sites In The Ukrainian CEZ in an area of 36 km Radius Around ChNPP Between July 1995 And September 1997. Sites Were Selected Using A Grid And The Approximate Distance Between Sampling Sites Was About 1.2 km.

The Collected Soil Samples Were Dried, Sieved Through a 1 mm Sieve And Homogenised For The Determination Of The Total Contents Of Radionuclides.

- DATA SOURCE:
- https://catalogue.ceh.ac.uk/documents/ae02f4e8-9486-4b47-93ef-e49dd9ddecd4

Spatial datasets of radionuclide contamination in the Ukrainian Chernobyl Exclusion Zone
THE DATA SET IS MAINTAINED BY THE UK CENTER FOR ECOLOGY AND HYDROLOGY WHICH IS REFERENCED FROM

TRansfer - Exposure - Effects (TREE) Integrating the science needed to underpin radioactivity assessments for humans and wildlife.

V.) PRE-PROCESSING AND PROCESS

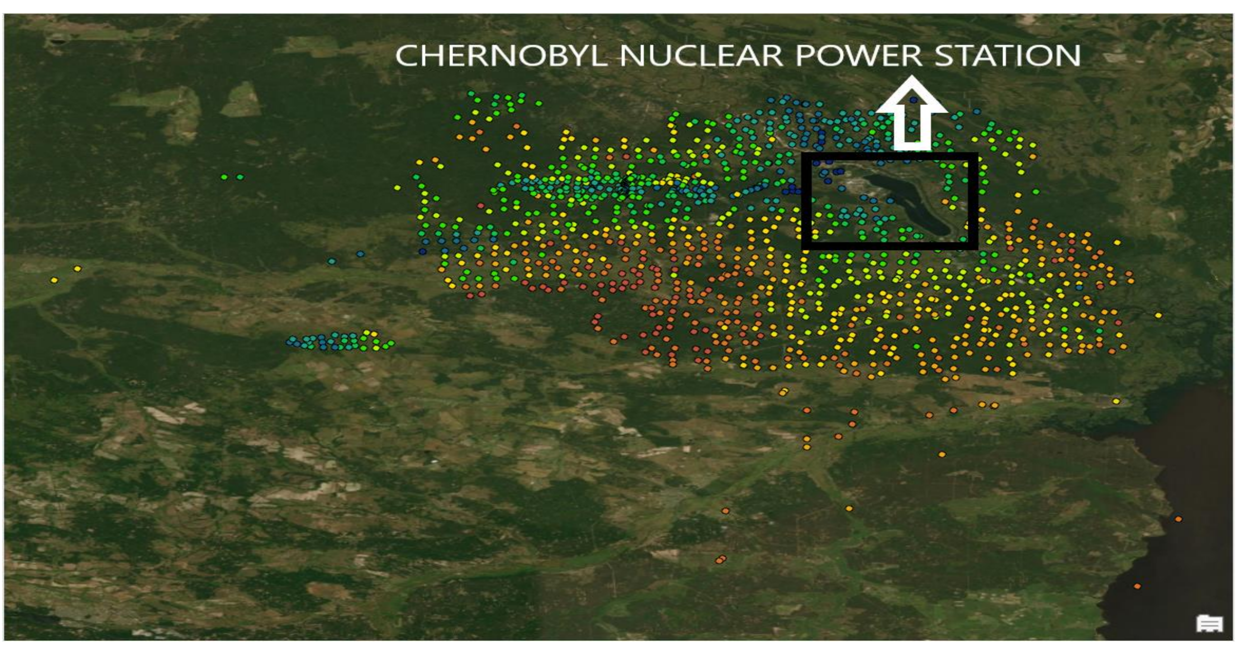
1) LOAD DATA (XY TABLE) WITH GEOGRAPHIC COORDINATE SYSTEM GCS WGS 1984

2) PROJECT DATA ONTO UTM COORDINATE UTM BGS2005_UTM_zone_34N (projection is the means by which you display the coordinate system and your data on a flat surface)

Spatial Reference

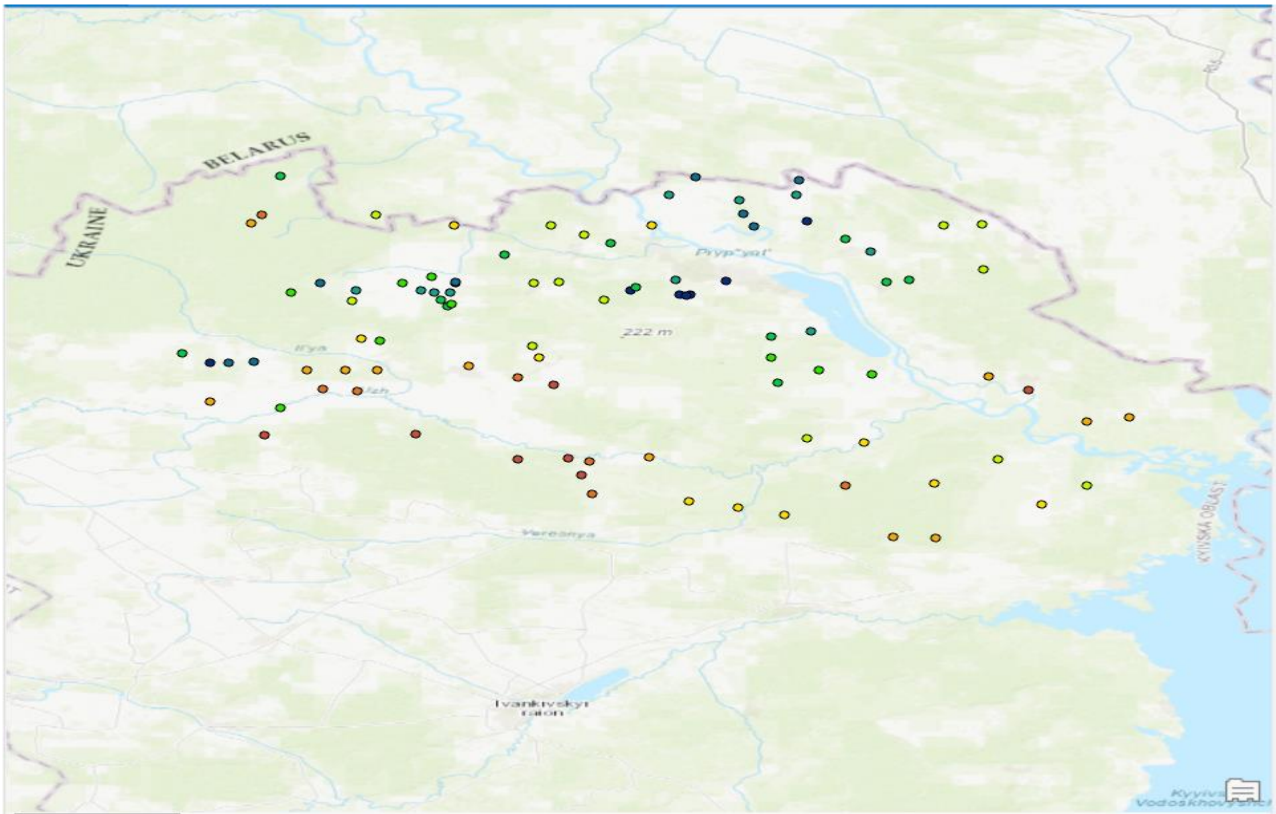
Projected Coordinate System	BGS2005 UTM zone 34N
Projection	Transverse Mercator
WKID	7803
Authority	EPSG
Linear Unit	Meters (1.0)
False Easting	500000.0
False Northing	0.0
Central Meridian	21.0
Scale Factor	0.9996
Latitude Of Origin	0.0

Geographic coordinate system	BGS2005
WKID	7798
Authority	EPSG
Angular Unit	Degree (0.0174532925199433)
Prime Meridian	Greenwich (0.0)
Datum	Bulgaria Geodetic System 2005
Spheroid	GRS 1980
Semimajor Axis	6378137.0
Semiminor Axis	6356752.314140356
Inverse Flattening	298.257222101



3) SUBSET 110 POINTS AND THEN SELECT THE POINTS THAT ARE NOT SPATIALLY IN THE RANGE OF OTHER POINTS (LONE POINTS FAR AWAY FROM CLUSTER) AND THEN DELETE THEM UNTIL YOU HAVE 100 POINTS.

SUBSET DATA POINTS



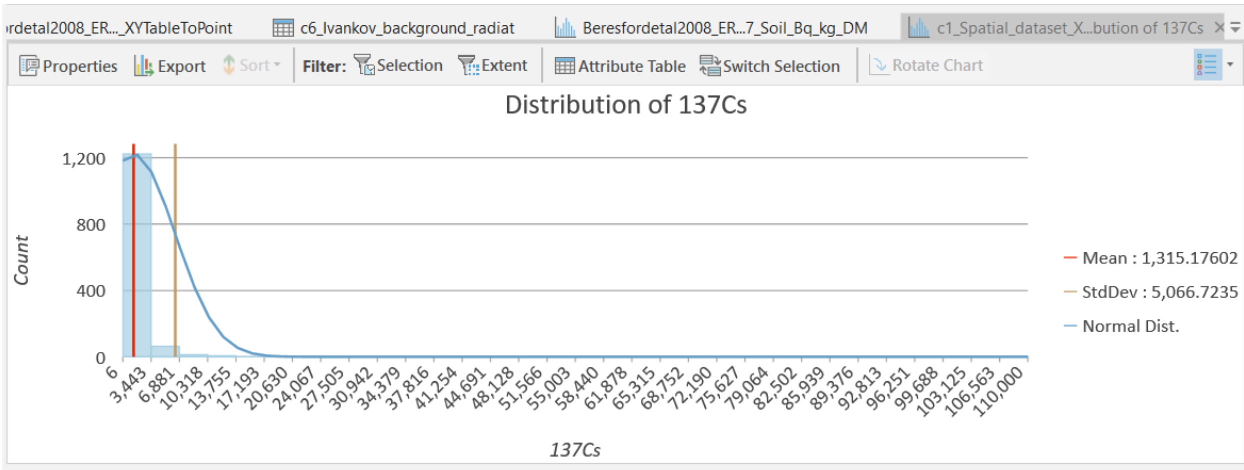
4) FROM ANALYSIS, SELECT GEOSTATISTICAL ANALYSIS WIZARD. NOW SELECT SOURCE DATASET AND THEN FILL IN DATA FIELD (CS- 137).

5) SELECT ORDINARY KRIGING (PREDICTION) WITH TRANSFORMATION TYPE AS LOG. (SINCE CESIUM DATA IS NOT NORMALLY DISTRIBUTED)

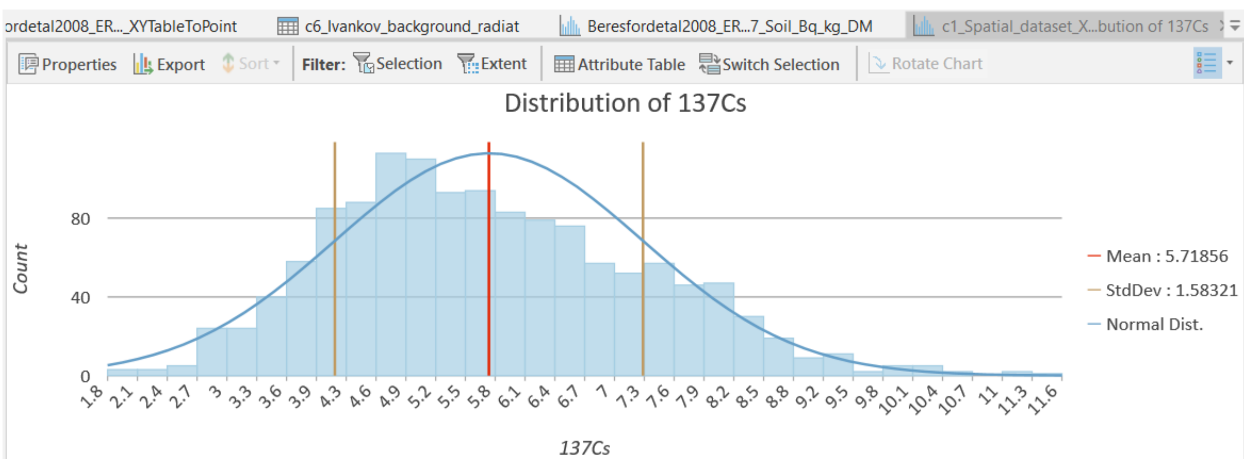
THE DATA HAS LEFT SKEWERED DISTRIBUTION SINCE ITS RANGE (110,000 MILLI SEWERTS) IS VERY MUCH HIGHER THAN THE AVERAGE DISTRIBUTION (12200 MILLI SEWERTS).

SO TRANSFORMING IT INTO DISCRETE BINS HELPS US ANALYZE THE DATA CORRECTLY. THIS TRANSFORMATION IS DONE THROUGH LOG TRANSFORMATION.

ACTUAL DISTRIBUTION



LOG TRANSFORMED DATA



7) NOW TWEAK WITH THE MODELS BY CHANGING THE

A) LAG SIZE

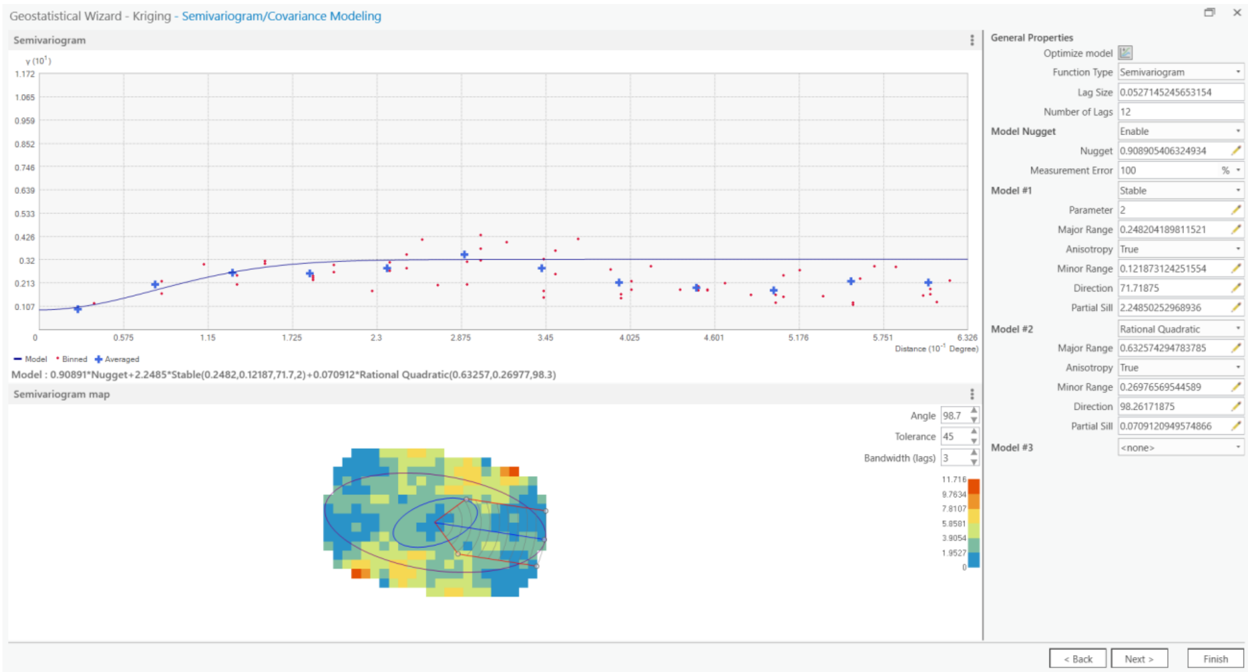
(CHANGING IT CHANGES THE BIN SIZE AND THE DATA GETS DIVIDED INTO DIFFERENT BINS SIZE THEREBY CHANGING THE SHAPE OF THE SEARCH NEIGHBOUR HOOD AND THE NUMBER OF POINTS IN THE SEARCH NEIGHBORHOOD WHICH CHANGES)

B) CHANGE THE OTHER PARAMETERS LIKE THE MODEL USED

(GAUSSIAN, EXPONENTIAL, STABLE, RELATIONAL QUADRATIC, HOLE EFFECT, K BESSEL, J BESSEL, CIRCULAR, SPHERICAL, TETRA SPHERICAL, PENTA SPHERICAL)

C) NOW SEARCH THE DIRECTION OF MAXIMUM SPATIAL CONTINUITY (THE POINTS LIE UNDER THE MODEL IN DIRECTION OF MAXIMUM SPATIAL CONTINUITY)

DIRECTION OF MAXIMUM SPATIAL CONTINUITY

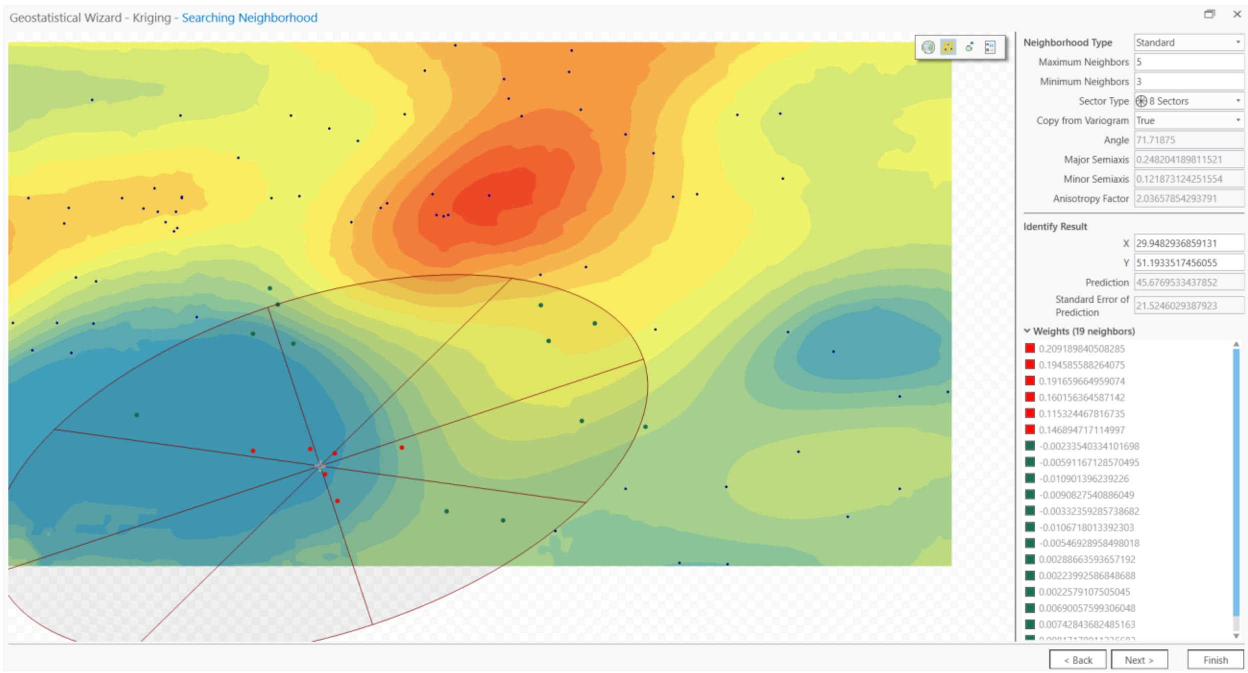


DIRECTION OF MINIMUM SPATIAL CONTINUITY

D) NOW CHANGE THE MINIMUM AND MAXIMUM NEIGHBOURHOOD AND SECTOR TYPE (8 SECTOR , 4 SECTOR, 4 SECTOR WITH 45 DEGREE, 1 SECTOR). BY CHANGING THE NEIGHBOURHOOD TYPE IT CHANGES THE NUMBER OF NEIGHBOURS.

WITH RESPECT TO MY DATASET THE FOLLOWING PATTERNS WERE OBSERVED:

(using the 4,8 Sector Neighborhood helped in Reducing the estimate of the Average Standard Error and using the 4 sector Neighborhood with 45 degree offset resulted in increasing the estimate of the Average Standard Error)

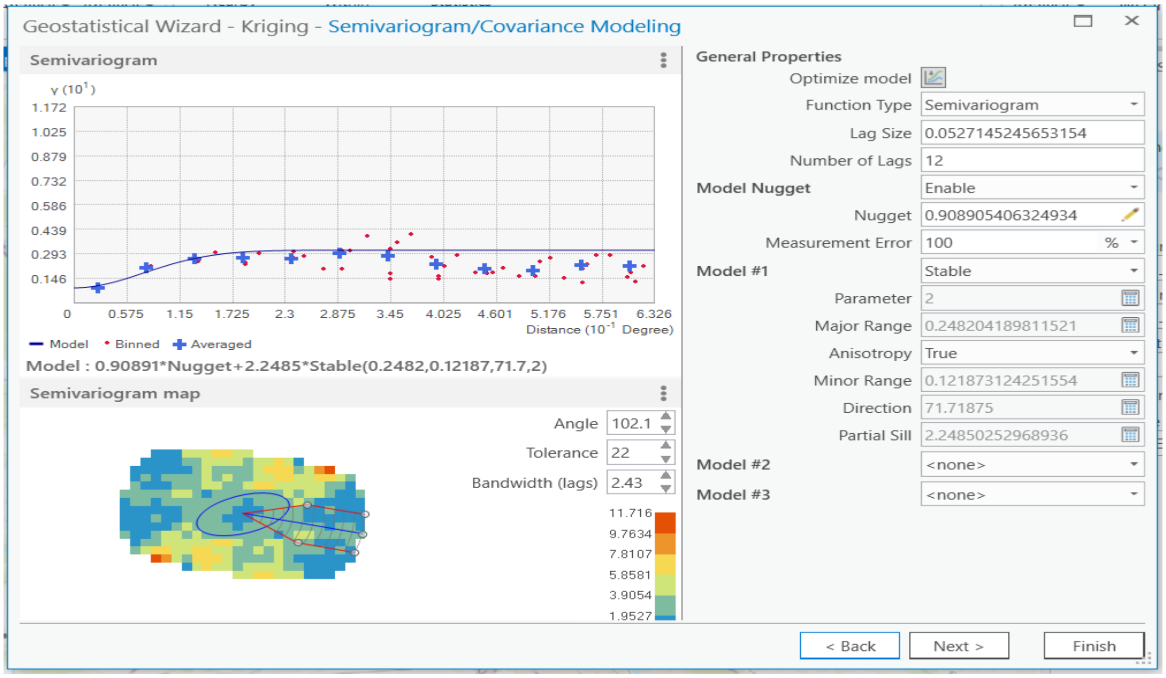


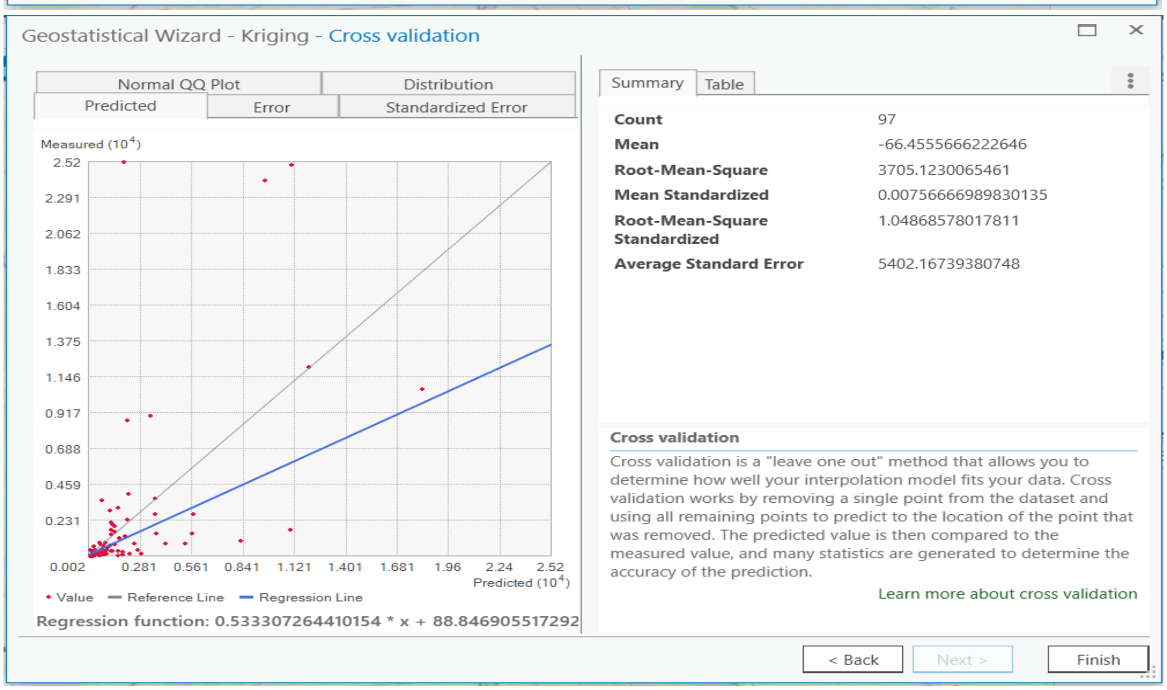
E) AFTER EACH CHANGE REVIEW THE CHANGES IN THE ERROR RATES:

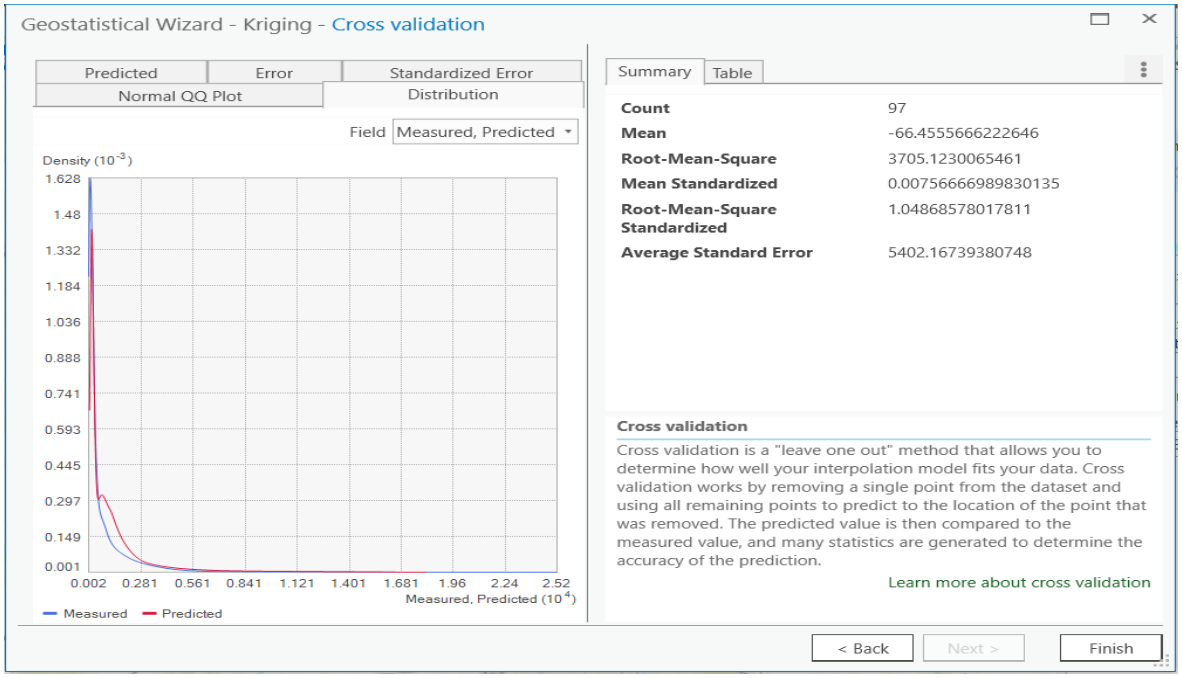
MEAN STANDARDIZED ERROR: AS CLOSE TO 0 AS POSSIBLE
ROOT MEAN SQUARE STANDARDIZED ERROR: AS CLSOE TO 1 AS POSSIBLE
ROOT MEAN SQUARE AND AVERAGE STANDARD ERROR AS CLOSE TO EACH OTHER AS POSSIBLE

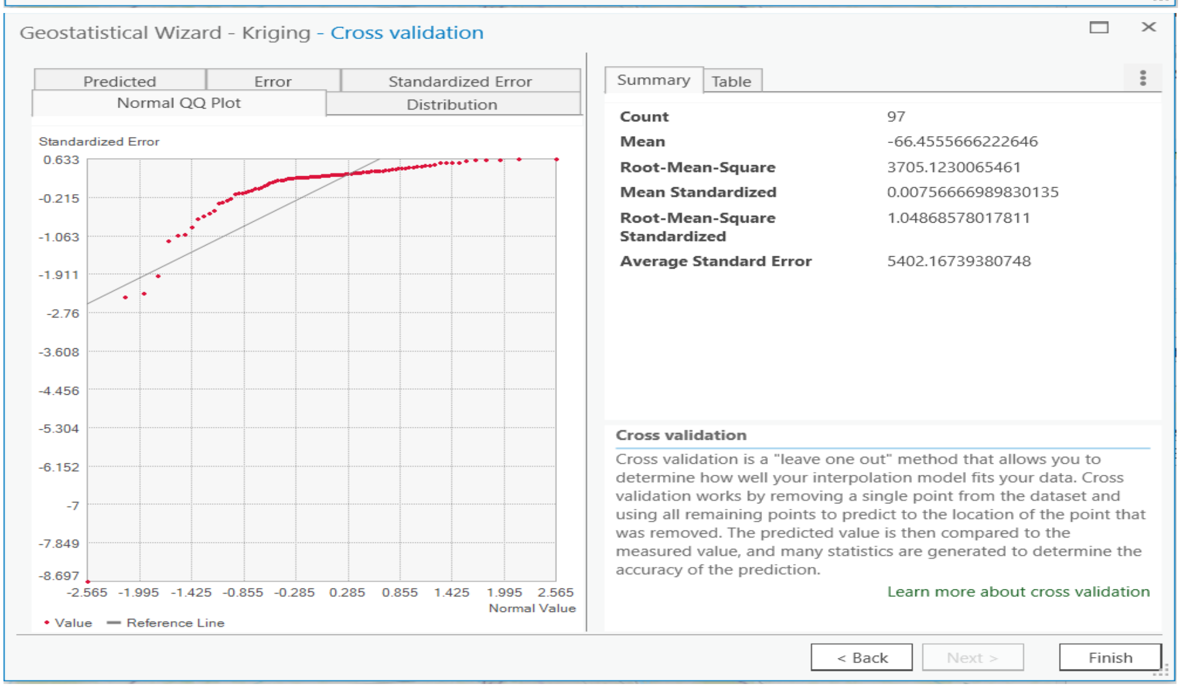
F) WE OBSERVE THAT WE GET A MUCH BETTER RESULT BY USING A 2 MODEL SEMIVARIOGRAM

1-MODEL RESULTS






Geostatistical Wizard - Kriging - Cross validation
Predicted
Error
Standardized Error
Normal QQ Plot
Distribution
Field Measured, Predicted
Density (10^{-3})
1.628
1.48
1.332
1.184
1.036
0.888
0.741
0.593
0.445
0.297
0.149
0.001
0.002 0.281 0.561 0.841 1.121 1.401 1.681 1.96 2.24 2.52
Measured, Predicted (10^{4})
Measured
Predicted
Summary
Table
Count 97
Mean -66.4555666222646
Root-Mean-Square 3705.1230065461
Mean Standardized 0.00756666989830135
Root-Mean-Square Standardized 1.04868578017811
Average Standard Error 5402.16739380748
Cross validation
Cross validation is a "leave one out" method that allows you to determine how well your interpolation model fits your data. Cross validation works by removing a single point from the dataset and using all remaining points to predict to the location of the point that was removed. The predicted value is then compared to the measured value, and many statistics are generated to determine the accuracy of the prediction.
Learn more about cross validation
< Back
Next >
Finish


Geostatistical Wizard - Kriging - Cross validation
Predicted
Error
Standardized Error
Normal QQ Plot
Distribution
Standardized Error
0.633
-0.215
-1.063
-1.911
-2.76
-3.608
-4.456
-5.304
-6.152
-7
-7.849
-8.697
-2.565 -1.995 -1.425 -0.855 -0.285 0.285 0.855 1.425 1.995 2.565
Normal Value
Value
Reference Line
Summary
Table
Count 97
Mean -66.4555666222646
Root-Mean-Square 3705.1230065461
Mean Standardized 0.00756666989830135
Root-Mean-Square Standardized 1.04868578017811
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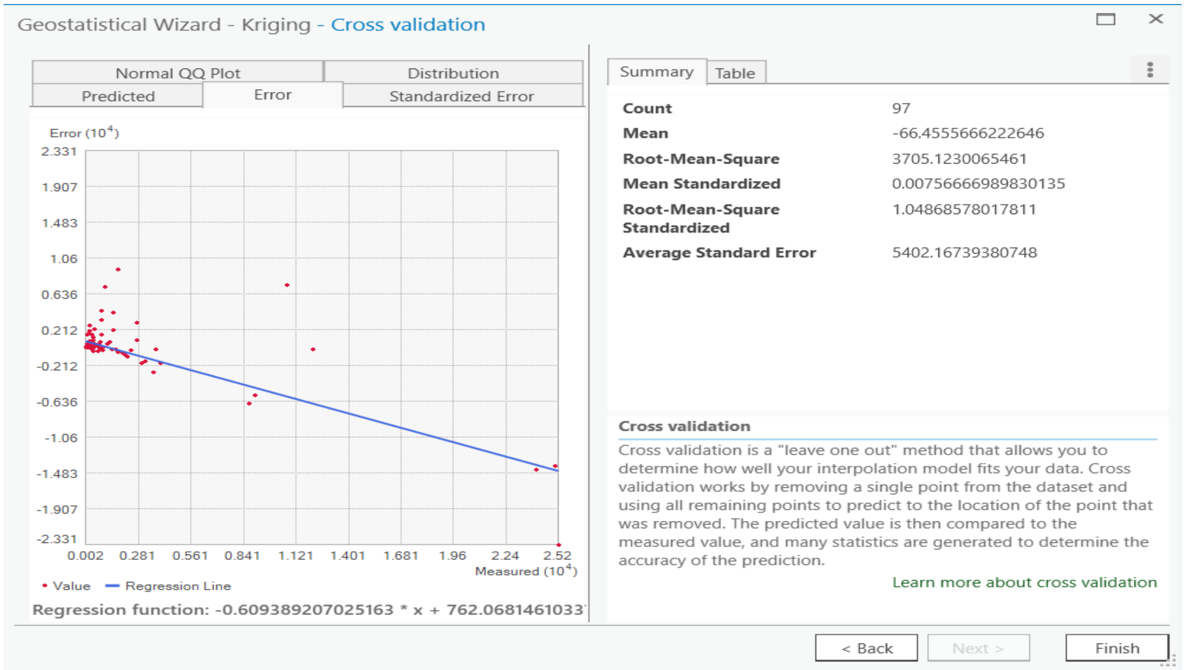
Finish


Geostatistical Wizard - Kriging - Cross validation
Normal QQ Plot
Distribution
Predicted
Error
Standardized Error
Error (10^4)
2.331
1.907
1.483
1.06
0.636
0.212
-0.212
-0.636
-1.06
-1.483
-1.907
-2.331
0.002 0.281 0.561 0.841 1.121 1.401 1.681 1.96 2.24 2.52
Measured (10^4)
Value
Regression Line
Regression function: -0.609389207025163 * x + 762.0681461033
Summary
Table
Count 97
Mean -66.4555666222646
Root-Mean-Square 3705.1230065461
Mean Standardized 0.00756666989830135
Root-Mean-Square Standardized 1.04868578017811
Average Standard Error 5402.16739380748
Cross validation
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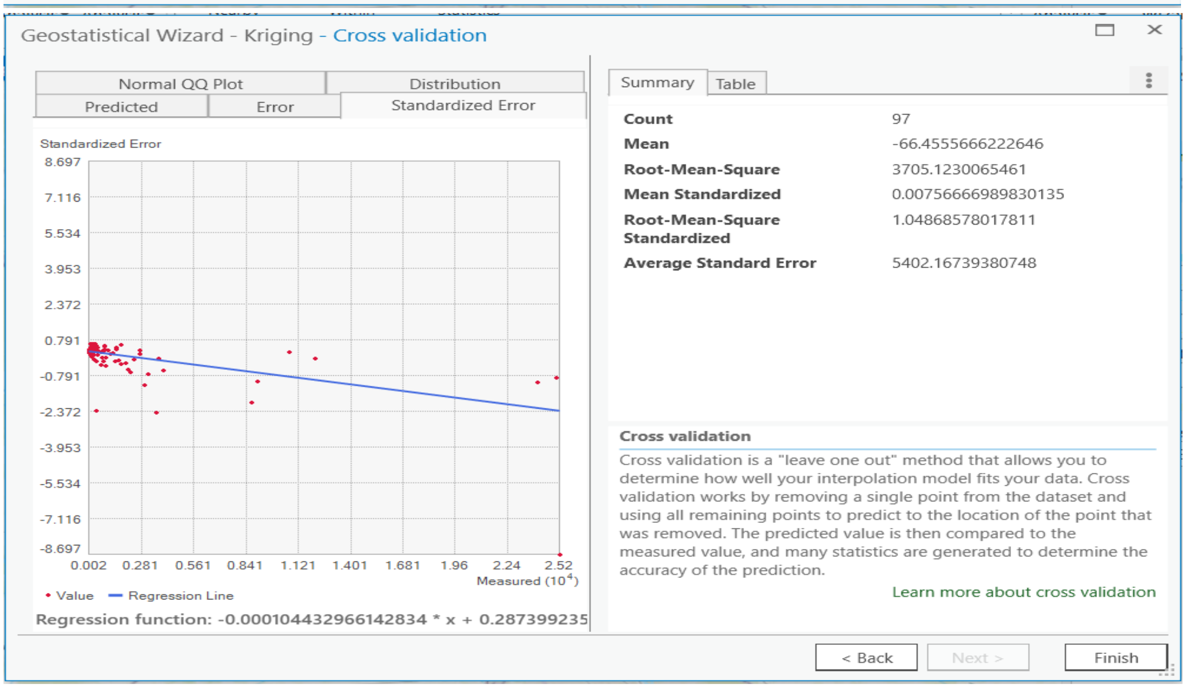
Next >
Finish


Geostatistical Wizard - Kriging - Cross validation
Normal QQ Plot
Distribution
Predicted
Error
Standardized Error
Standardized Error
8.697
7.116
5.534
3.953
2.372
0.791
-0.791
-2.372
-3.953
-5.534
-7.116
-8.697
0.002 0.281 0.561 0.841 1.121 1.401 1.681 1.96 2.24 2.52
Measured (10^4)
Value
Regression Line
Regression function: -0.000104432966142834 * x + 0.287399235
Summary
Table
Count 97
Mean -66.4555666222646
Root-Mean-Square 3705.1230065461
Mean Standardized 0.00756666989830135
Root-Mean-Square Standardized 1.04868578017811
Average Standard Error 5402.16739380748
Cross validation
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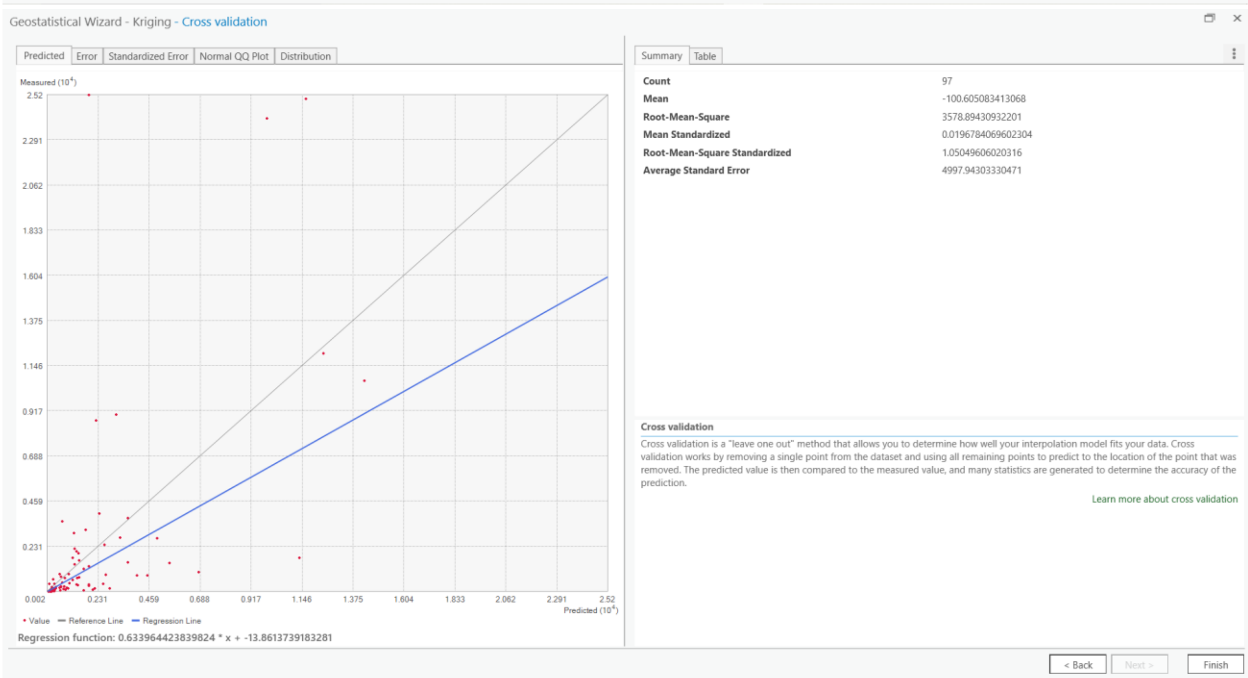
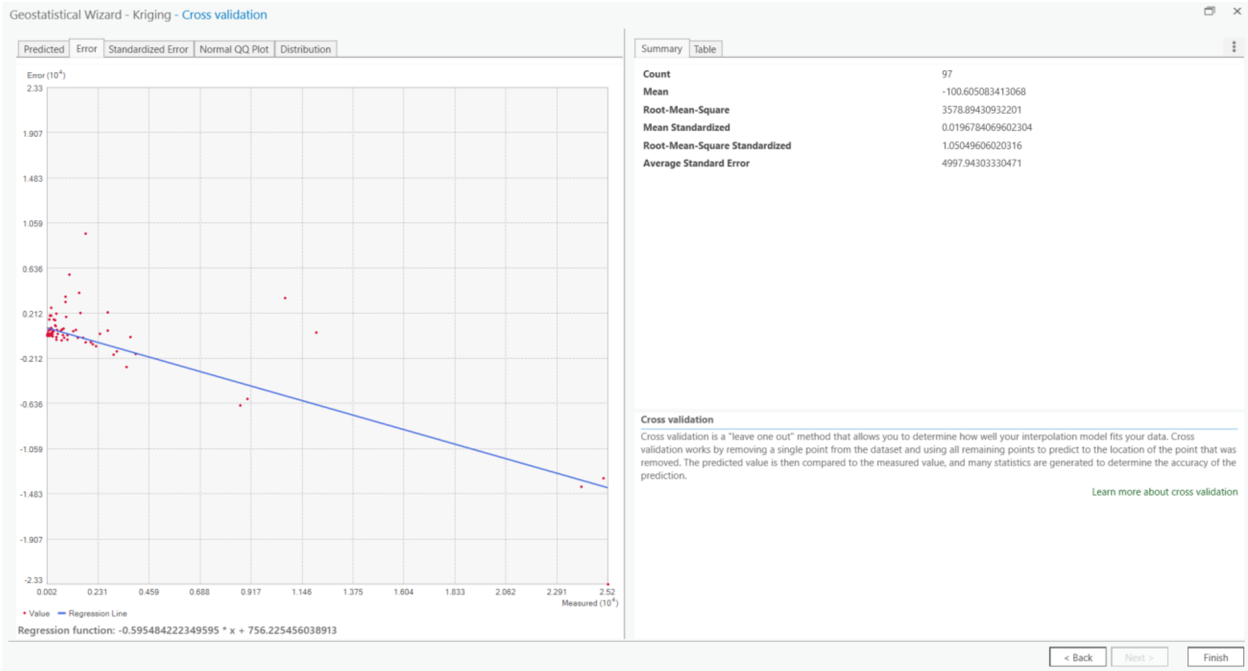
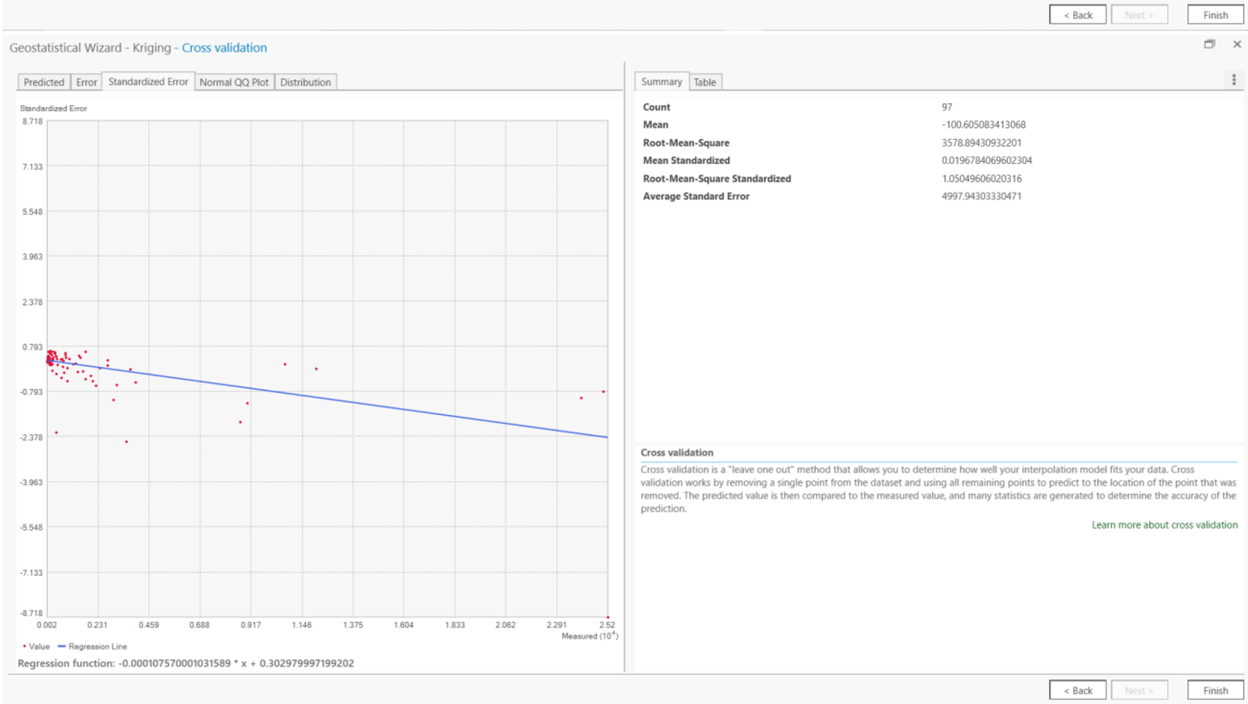
Learn more about cross validation
< Back
Next >
Finish

2-MODEL RESULTS




Geostatistical Wizard - Kriging - Cross validation
Predicted
Error
Standardized Error
Normal QQ Plot
Distribution
Error (10^4)
2.33
1.907
1.483
1.059
0.636
0.212
-0.212
-0.636
-1.059
-1.483
-1.907
-2.33
0.002
0.231
0.459
0.688
0.917
1.146
1.375
1.604
1.833
2.062
2.291
2.52
Measured (10^4)
Value
Regression Line
Regression function: -0.595484222349595 * x + 756.225456038913
Summary
Table
Count
97
Mean
-100.605083413068
Root-Mean-Square
3578.89430932201
Mean Standardized
0.0196784069602304
Root-Mean-Square Standardized
1.05049606020316
Average Standard Error
4997.94303330471
Cross validation
Cross validation is a "leave one out" method that allows you to determine how well your interpolation model fits your data. Cross validation works by removing a single point from the dataset and using all remaining points to predict to the location of the point that was removed. The predicted value is then compared to the measured value, and many statistics are generated to determine the accuracy of the prediction.
Learn more about cross validation
< Back
Next >
Finish


Geostatistical Wizard - Kriging - Cross validation
Predicted
Error
Standardized Error
Normal QQ Plot
Distribution
Standardized Error
8.718
7.133
5.548
3.963
2.378
0.793
-0.793
-2.378
-3.963
-5.548
-7.133
-8.718
0.002
0.231
0.459
0.688
0.917
1.146
1.375
1.604
1.833
2.062
2.291
2.52
Measured (10^4)
Value
Regression Line
Regression function: -0.000107570001031589 * x + 0.302979997199202
Summary
Table
Count
97
Mean
-100.605083413068
Root-Mean-Square
3578.89430932201
Mean Standardized
0.0196784069602304
Root-Mean-Square Standardized
1.05049606020316
Average Standard Error
4997.94303330471
Cross validation
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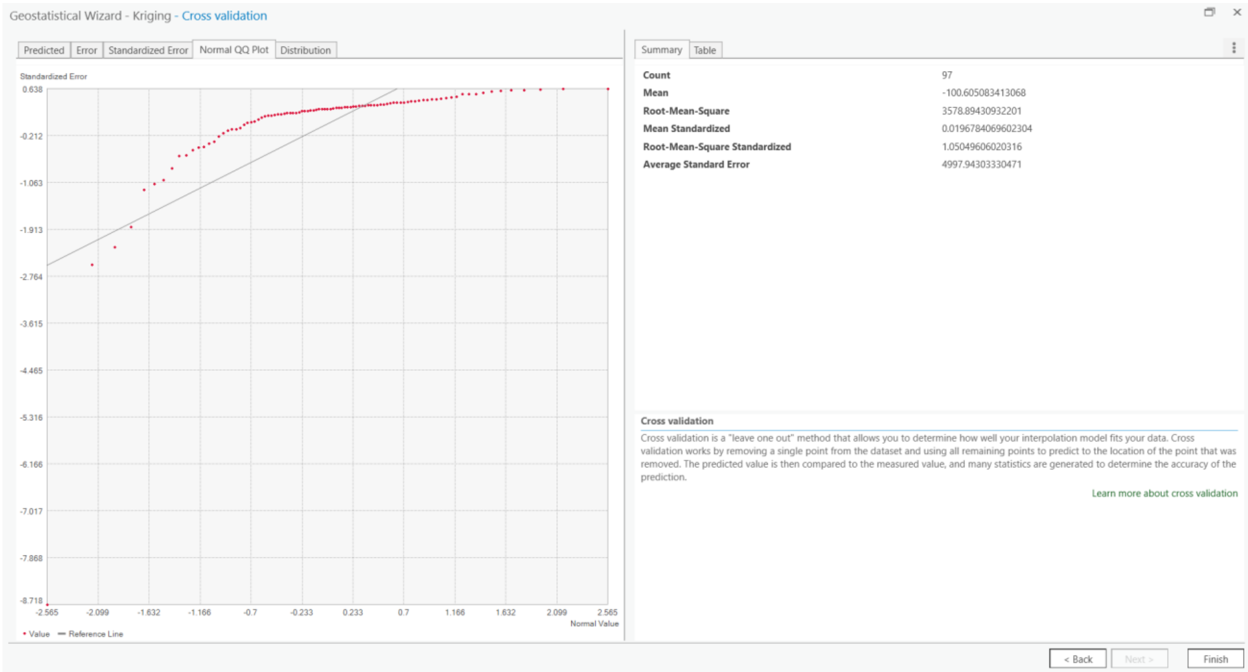
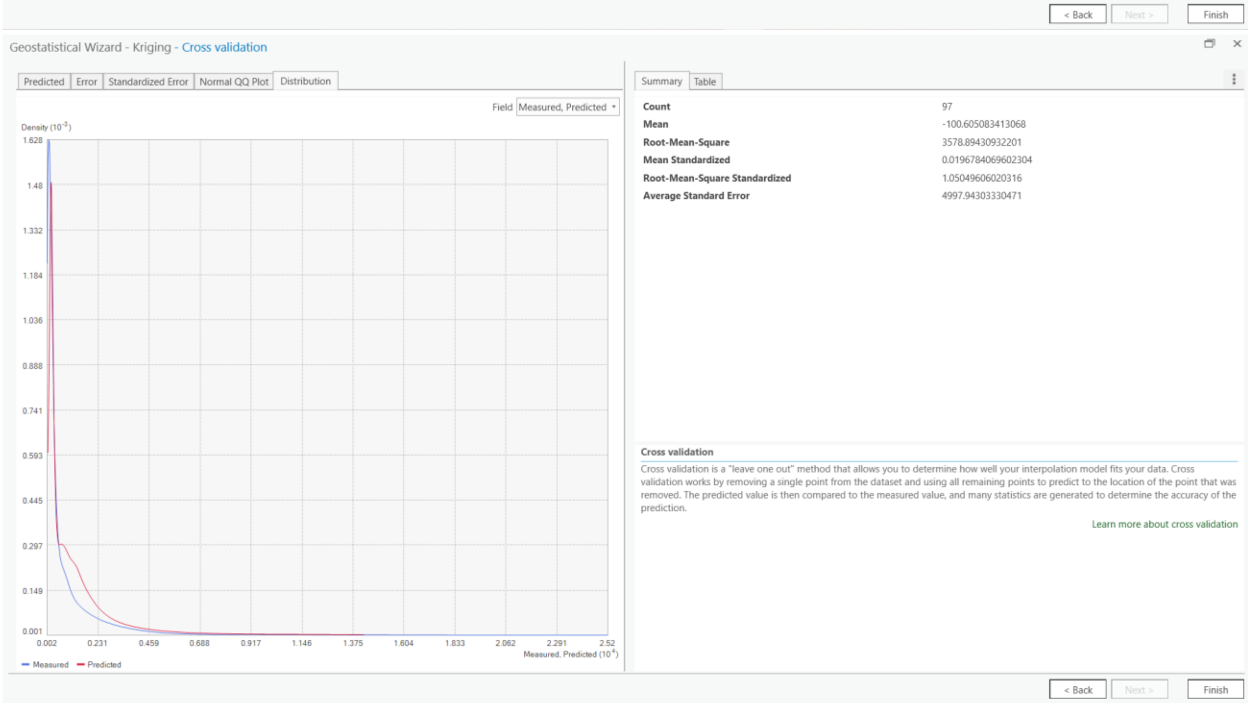
Next >
Finish

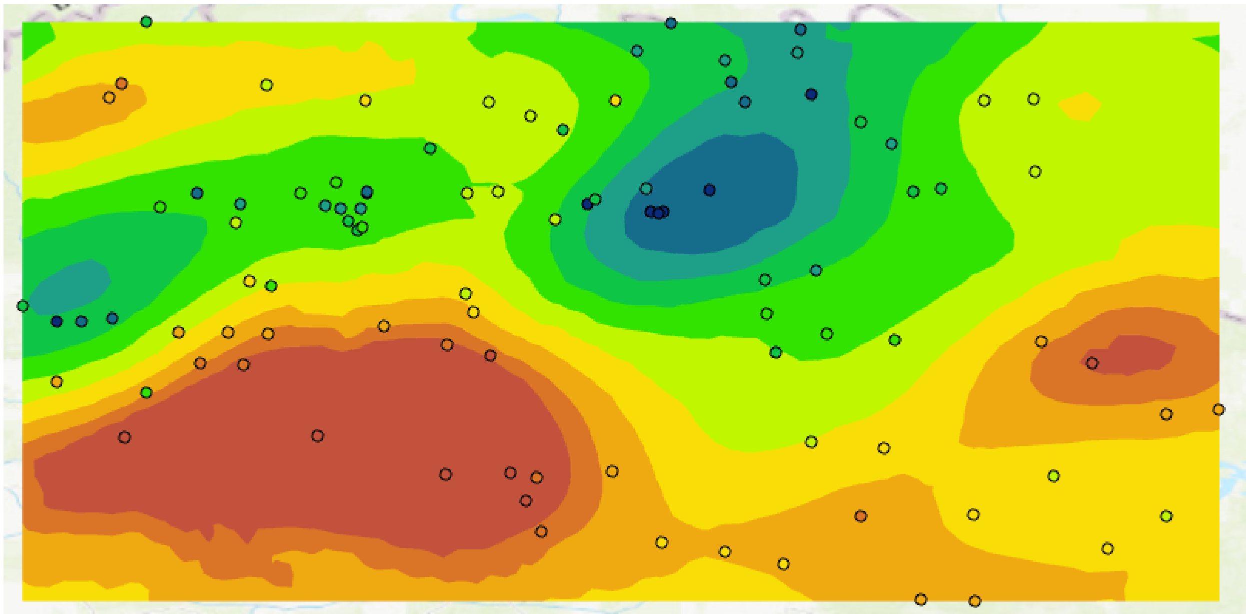


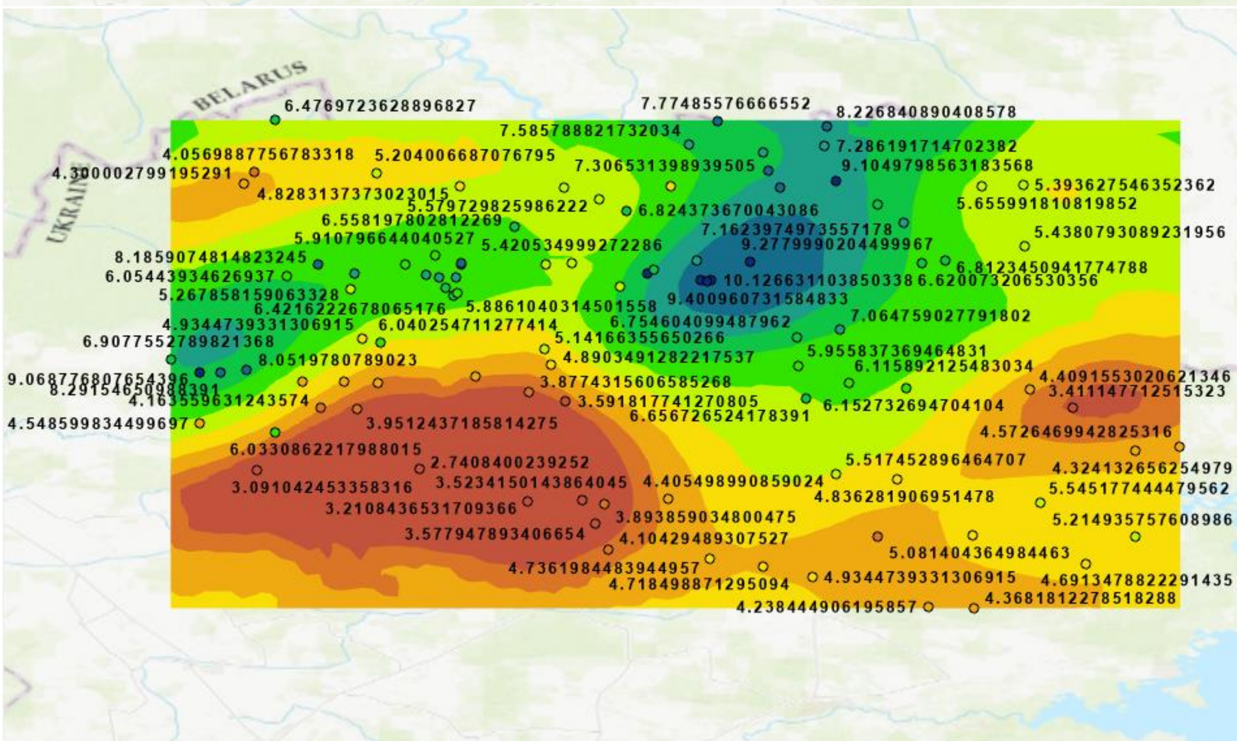


G.) AFTER CLICKING FINISH WE GET A REPORT OF THE RESULTS. CLICK OK.

H.) NOW WE GET A KRIGING MAP

I.) WE OBSERVE A FAIR DEGREE OF ASSESSMENT. THERE ARE INHERENT FLAWS IN THE ASSESSMENT AS THE DATA IS NOT CONTINUOUS. IT IS HETEROGENEOUS AND HAS DISCRETE, UNPREDICTABLE AND LARGE VALUES BUT THE MODEL HAS BEEN SUCCESSFUL IN PREDICTING FAIR RESULTS.




BELARUS
6.4769723628896827
7.77485576666552
8.226840890408578
7.585788821732034
7.286191714702382
4.0569887756783318
5.204006687076795
7.306531398939505
9.1049798563183568
4.300002799195291
5.393627546352362
4.8283137373023015
5.579729825986222
5.655991810819852
6.824373670043086
6.558197802812269
7.1623974973557178
5.4380793089231956
5.910796644040527
5.420534999272286
9.2779990204499967
8.1859074814823245
6.8123450941774788
6.05443934626937
10.126631103850338
6.620073206530356
5.267858159063328
9.400960731584833
6.4216222678065176
5.8861040314501558
7.064759027791802
4.9344739331306915
6.040254711277414
6.754604099487962
6.9077552789821368
5.14166355650266
5.955837369464831
8.0519780789023
4.8903491282217537
6.115892125483034
9.068776807654396
8.29154650988391
4.163559631243574
3.8774315606585268
4.4091553020621346
3.411147712515323
3.5918177741270805
6.152732694704104
4.548599834499697
3.9512437185814275
6.656726524178391
4.5726469942825316
6.0330862217988015
2.7408400239252
5.517452896464707
4.324132656254979
3.091042453358316
3.5234150143864045
4.405498990859024
4.836281906951478
5.545177444479562
3.2108436531709366
3.893859034800475
5.214935757608986
3.577947893406654
4.10429489307527
5.081404364984463
4.7361984483944957
4.7184988871295094
4.9344739331306915
4.6913478822291435
4.238444906195857
4.3681812278518288

c1_Spatial_dataset_XYTableToPoint1_training2

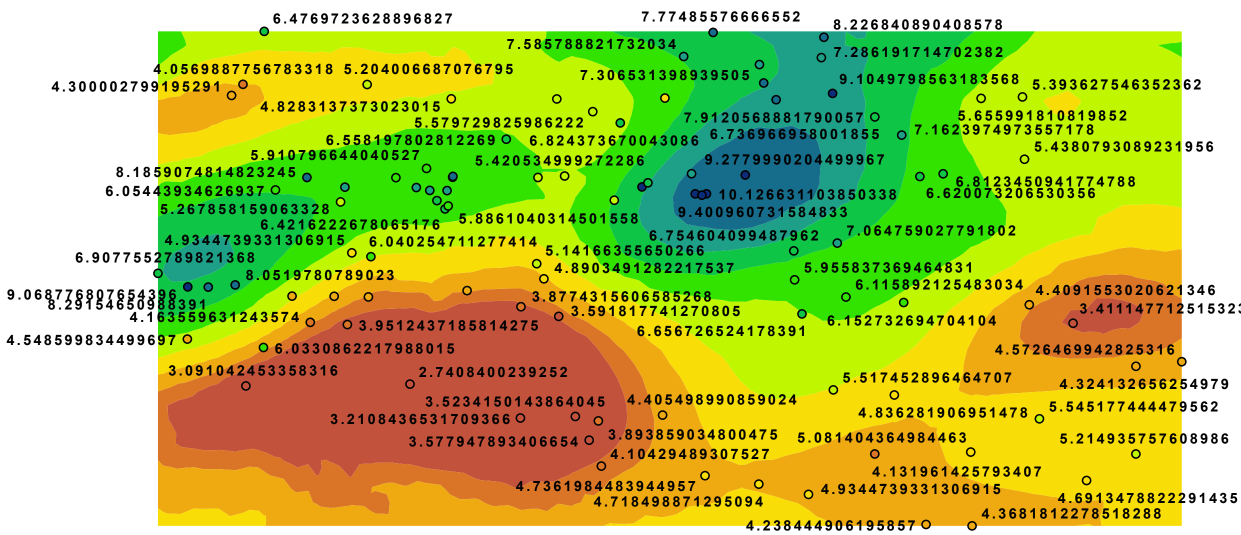
Log 137Cs

- ≤1.560
- ≤1.808
- ≤1.986
- ≤2.207
- ≤2.456
- ≤2.672
- ≤3.000
- ≤3.316
- ≤3.601
- ≤4.401

Kriging

Filled Contours

- 15.5 - 66.872988
- 66.872988 - 89.967703
- 89.967703 - 141.34069
- 141.34069 - 255.61722
- 255.61722 - 509.8194
- 509.8194 - 1,075.2789
- 1,075.2789 - 2,333.114
- 2,333.114 - 5,131.1026
- 5,131.1026 - 11,355.082
- 11,355.082 - 25,200
- NoData

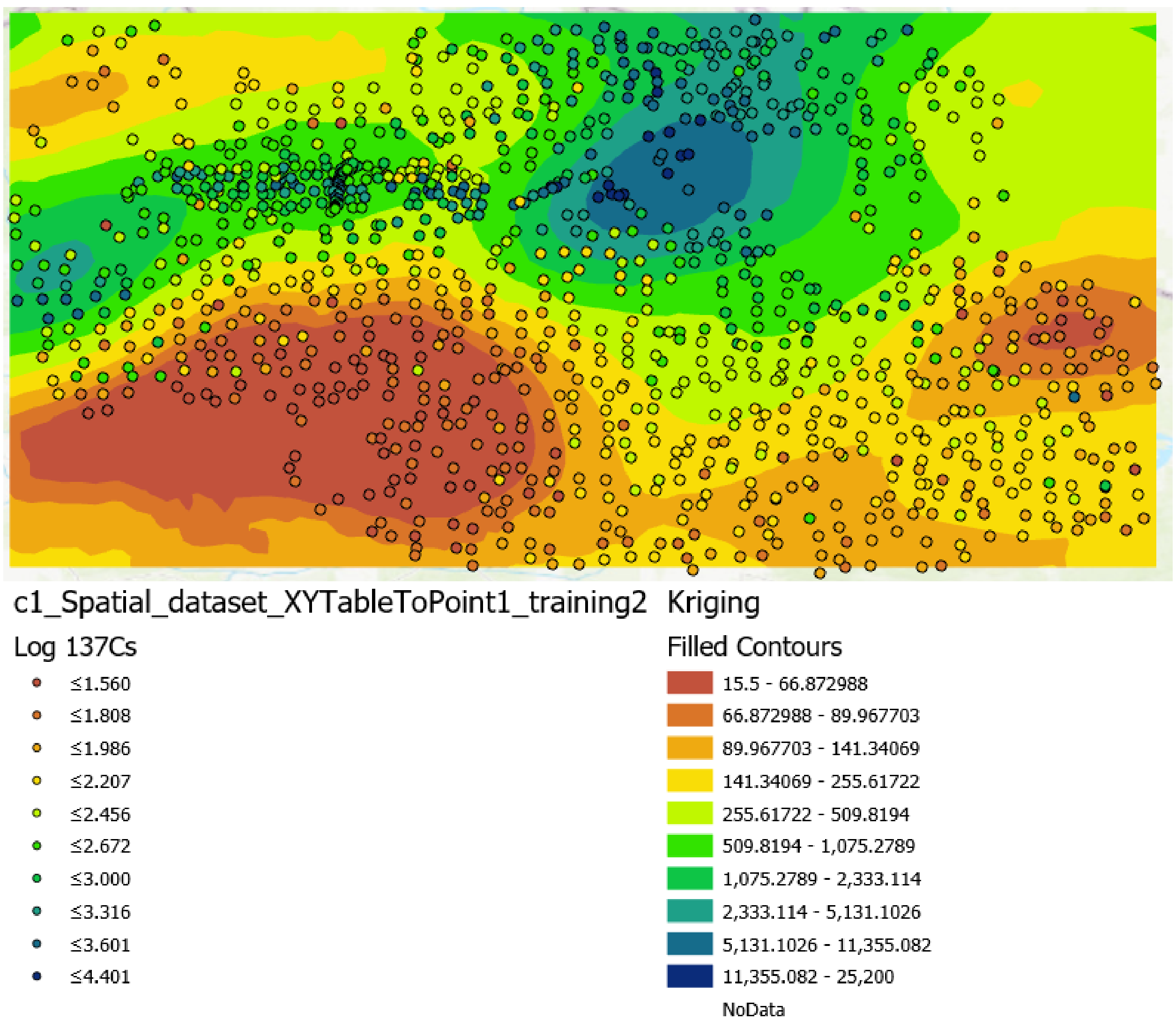


Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

VI.) RESULTS AND DISCUSSION

We Observe That In Spite Of Changing Models, Search Neighborhood, Anisotropy, lag Size And Even The Subset We Observe That The Results Are Not Very Satisfactory. The Average Standard Error Is Greater Than The Root Mean Square The Variable Is Over Estimated And We Are Not Able To Get Better Results. The Major Reason That Can Be Attributed To It Is The Presence Of Large Quantity Of Radiation In The North And The West Of The Reactors Which Make Kriging Difficult. The Points Have Unequal Distribution With No Logical Spread. The Degree Of Radiation Depends On The Amount Of Chunk And The Size And Also On The Various Weathering Phenomenon Discussed Above. Due To The Accident There Was Huge Amounts Of Radio Active Debris That Got Spread In All The Directions. These Debris Have Either Low Or Very High Radiation Content. This Makes The Data Inconsistent And Unsuitable For kriging.

KRIGING MAP – ORIGINAL DATA SET



From The Map Above Which Contains The Original Data Points On A Kriging Map Tells Us That Kriging Has Done A Fair Job In Interpolating The Data And The Discrepancies Is Due To The Outliers And Cannot Be Determined And Also This Leads To Errors In The Model.

From The Data We Can Observe That Highest Concentration Of Cesium (Blue DOTS) Is Found At The North And The West Of The Reactor. While Other Areas Have Relatively Lower Concentrations Of Cesium.

VI. CONCLUSION

KRIGING HAS BEEN SUCCESSFUL IN ASSESSING AND INTERPOLATING DATA WITH NO LOGICAL SPATIAL AND TEMPORAL CORRELATION. THE UNCERTANITY IN THE DATA IS THE CAUSE FOR THE ERROR.

THE DATA COULD BE BETTER UNDERSTOOD BY USING POISSON KRIGING BUT IN ORDER FOR IT TO WORK IT NEEDS DATA THAT IS NEARBY TO ONE ANOTHER. THIS DATA IS TAKEN AT A DISTANCE OF 1.2KMS EACH. AND THIS IS NOT SUITABLE FOR INTERPOLATION THROUGH POISSON KRIGING. IT NEEDS A DISTANCE OF LESS THAN 3 METERS TO MODEL A DATA THAT IS SO RANDOM. WITH THE AVERAGE DISTANCE GREATER THAN 1.2 KMS ITS COVARIANCE MATRIX IS ESSENTIALLY HAVING NO CORRELATION AND ITS RESULTS ARE EVEN WORSE THAN THE ORDINARY KRIGING.

EVEN USING MEAN KRIGING DOESNOT GIVE MUCH BETTER RESULTS AS THE DATA IS VERY UNHARMONIOUS AND ALTHOUGH IT COULD POTENTIALLY GIVE BETTER RESULTS BUT THE IMPROVEMENT IS NOT VERY GREAT.ALSO THE DISTRIBUTION OF POINTS FROM WHERE DATA IS COLLECTED IS UNEVEN. THIS COULD ALSO BE A FACTOR IN THE DATA BEING SKEWED. THE DATA IS COLLECTED AT AN INTERVAL OF 2 YEARS WHICH IS HIGHLY UNRELIABLE AS THE RADIATION RATES CANNOT BE SAID TO BE ONLY DUE TO THE DEBRI FROM THE FALLOUT. THE WEATHER PHENOMENON COULD ADD EXTRA BACKGROUND RADIATION AT THE SAMPLED LOCATION. AS WE OBSERVE FROM OUR RESEARCH THAT DUE TO RAINS TEMPORARILY THE RADIATION RATES INCREASES.

IF THE DATA WAS TAKEN AT A CLOSER INTERVALS IN A SMALLER AMOUNT OF TIME FRAME THE RESULTS COULD BE BETTER INTERPRETED BUT DUE TO THE INEQUAL DISTRIBUTION OF DATA AND LACK OF DATA AT THE INITIAL STAGES OF EXPLOSION ITS HIGHLY DIFFICULT TO DETERMINE THE NATURE AND THE SPREAD OF THE DATA VERY ACCURATELY BUT ITS ENOUGH TO GET A GENERAL UNDERSTANDING ON THE DIRECTION OF WIND DURING EXPLOSION AND THE AREAS OF DANGER AROUND THE REACTOR.

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   https://core.ac.uk/download/pdf/29257859.pdf

2) **MAPPING RADIOACTIVITY FROM MONITORING DATA AUTOMATING THE CLASSICAL GEOSTATISTICAL APPROACH [Edzer J. Pebesma]**
   https://pdfs.semanticscholar.org/0aae/ae532f005e02a064a28a5253e05db5384676.pdf

3) **IDENTIFYING ANOMALOUS NUCLEAR RADIOACTIVE SOURCES USING POISSON KRIGING AND MOBILE SENSOR NETWORKS [Jifu Zhao, Zhe Zhang, Clair J. Sullivan]**
   https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0216131#references

4) **USING ORDINARY KRIGING TO MODEL RADIOACTIVE CONTAMINATION DATA [Elena Saveliena]**
   https://www.researchgate.net/publication/251001548_Using_Ordinary_Kriging_to_Model_Radioactive_Contamination_Data

5) **STUDY ON APPLICATION OF KRIGING TO EVALUATION OF RADIOACTIVITY CONCENTRATION FOR ENSURING COMPLIANCE WITH THE CRITERION OF SITE RELEASE [Tsutomu Ishigami, Taro Shimada]**
   https://www.tandfonline.com/doi/full/10.1080/00223131.2014.1001458

6) **SPATIAL ANALYSIS OF 137 CESIUM IN THE ENVIRONMENT [G. Dubois, P. Bossew]**
   https://www.researchgate.net/publication/261785269_Spatial_analysis_of_137Cs_in_the_environment_an_overview_on_the_current_experience

7) **DETECTION AND PARAMETER ESTIMATION OF MULTIPLE RADIOACTIVE SOURCES [Mark Morelande, Branko Ristic, Ajith Gunatilaka]**
   https://www.researchgate.net/publication/4301245_Detection_and_parameter_estimation_of_multiple_radioactive_sources

8) **THIRTY YEARS AFTER THE CHERNOBYL ACCIDENT: WHAT LESSONS HAVE WE LEARNT? [N.A.Beresford,S.Fesenko,A.Konoplev,L.Skuterud,J.T.Smith,G.Voigt]**
   https://www.sciencedirect.com/science/article/pii/S0265931X16300261#bib56