GEOESTADÍSTICA APLICADA A LA ESTIMACIÓN DE RECURSOS MINERALES

Tema: Caso de Estudio de un Depósito de Cu y Au

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PLATAFORMA DE APRENDIZAJE EN LINEA

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1. Introducción

1. Introducción

- El caso de estudio consiste en un conjunto de datos tomados de muestras de sondajes en tres dimensiones de una mina de cobre y oro, pero considerando el promedio en un intervalo en la vertical de 5 metros, para simplificar el ejemplo a dos dimensiones espaciales.

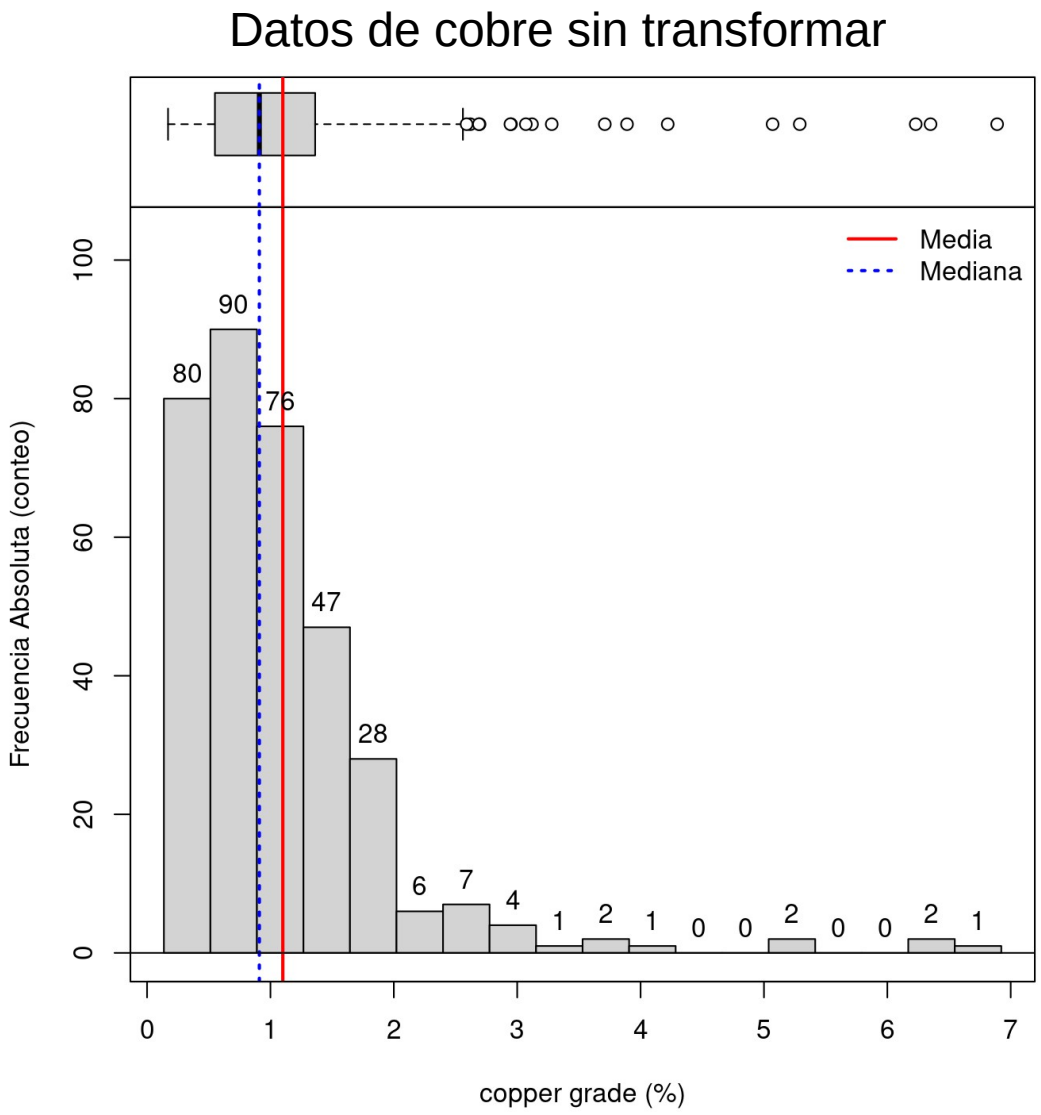
- Se considera el caso en 2D ya que permite de una manera práctica y simplificada mostrar la aplicación de la metodología sin pérdida de generalidad.

- La presentación imita el contenido del curso, y sirve de ilustración de la aplicación de la metodología Geoestadística a un caso de estudio para la Estimación de Recursos Mineros.

- A continuación se mostrará paso a paso cada una de las etapas de la metodología Geoestadística.

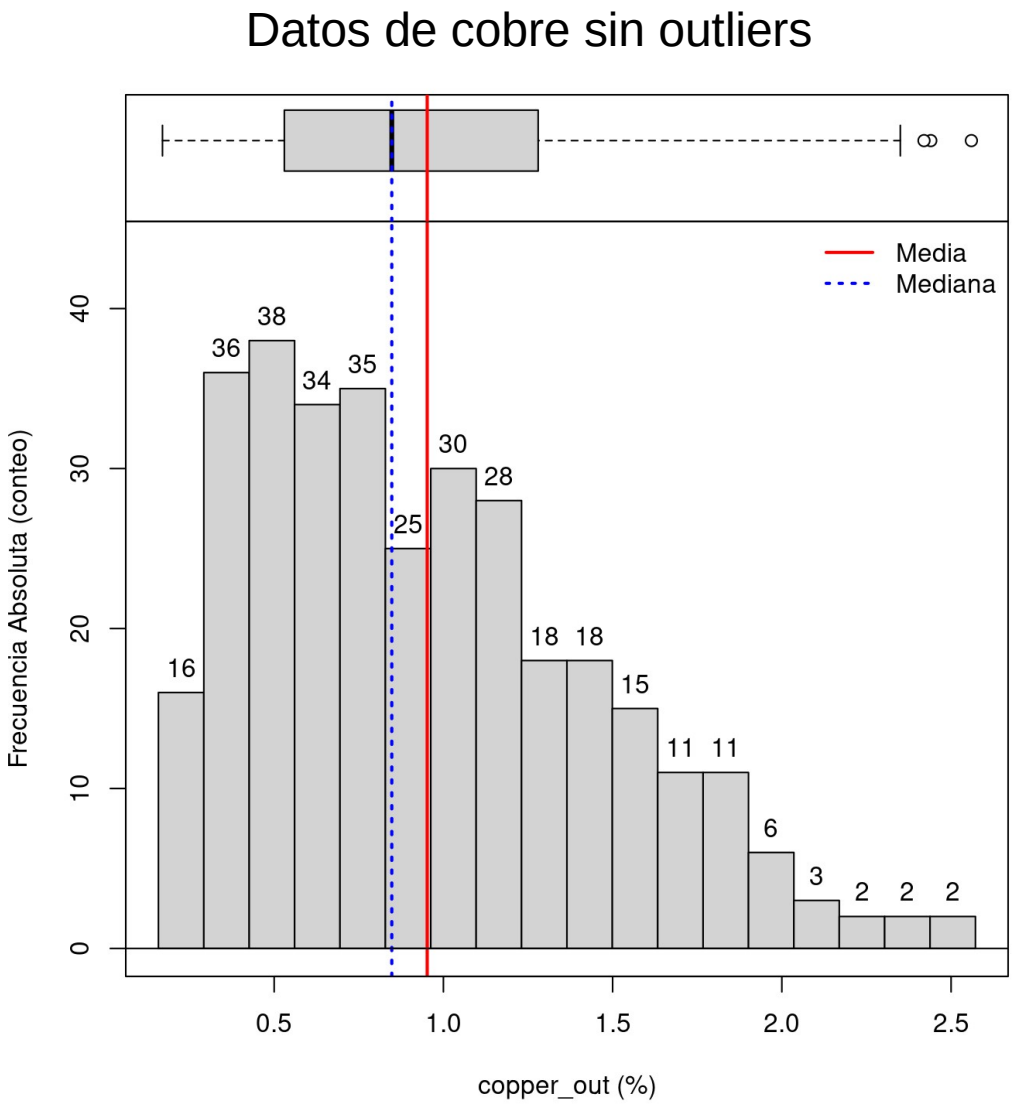
2. Análisis exploratorio de datos

2.1.1 Análisis univariado de cobre



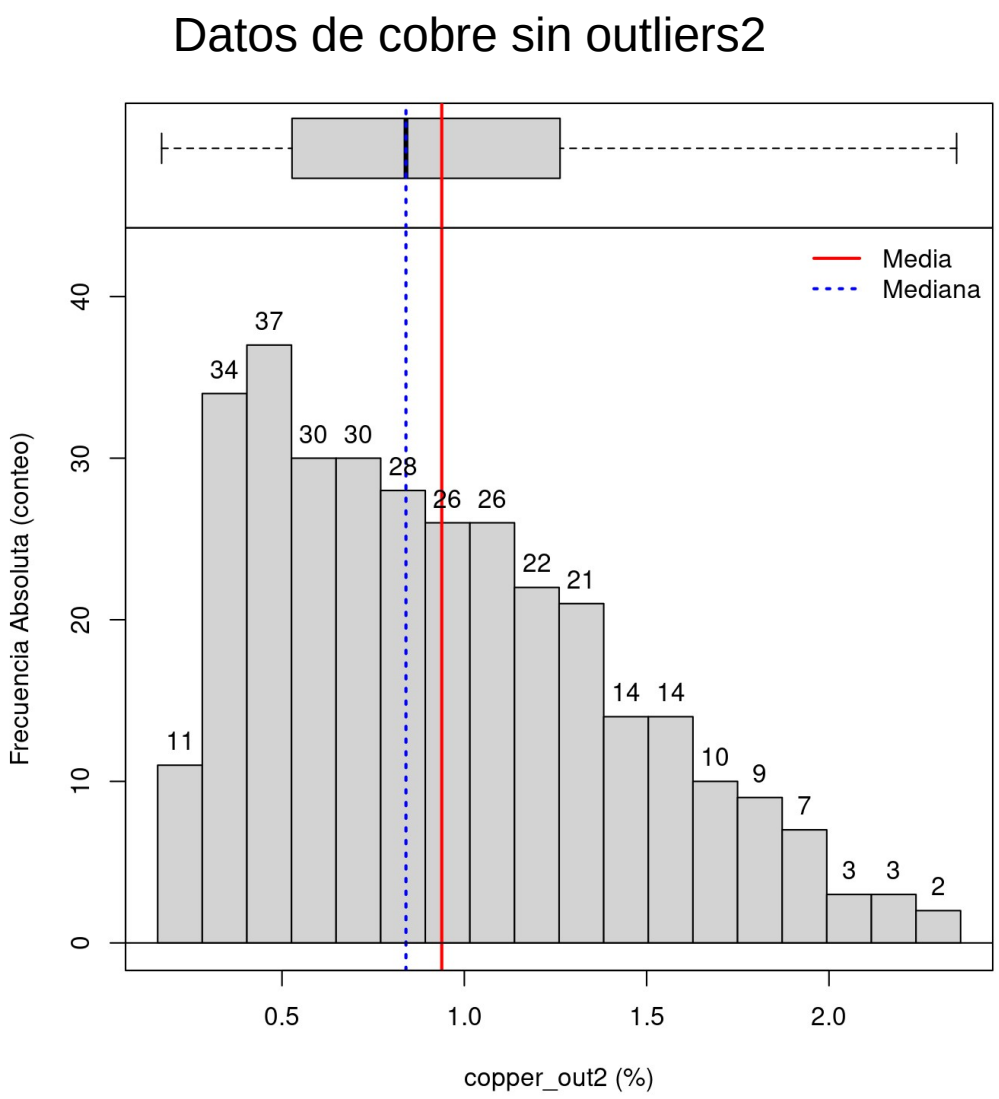
Estadística	Copper.Grade
No_muestras	347
Minimo	0.17
Cuartil_1er	0.55
Mediana	0.91
Media	1.10027
Cuartil_3er	1.3625
Maximo	6.89
Rango	6.72
Rango_Intercuartil	0.8125
Varianza	0.76863
Desv_Estandar	0.87671
Simetria	3.112
Curtosis	17.12323

2.1.1 Análisis univariado de cobre



Estadística	Copper_out.Grade
No_muestras	330
Minimo	0.17
Cuartil_1er	0.5312
Mediana	0.8475
Media	0.9521
Cuartil_3er	1.28
Maximo	2.56
Rango	2.39
Rango_Intercuartil	0.7488
Varianza	0.2569
Desv_Estandar	0.5069
Simetria	0.6959
Curtosis	2.8653

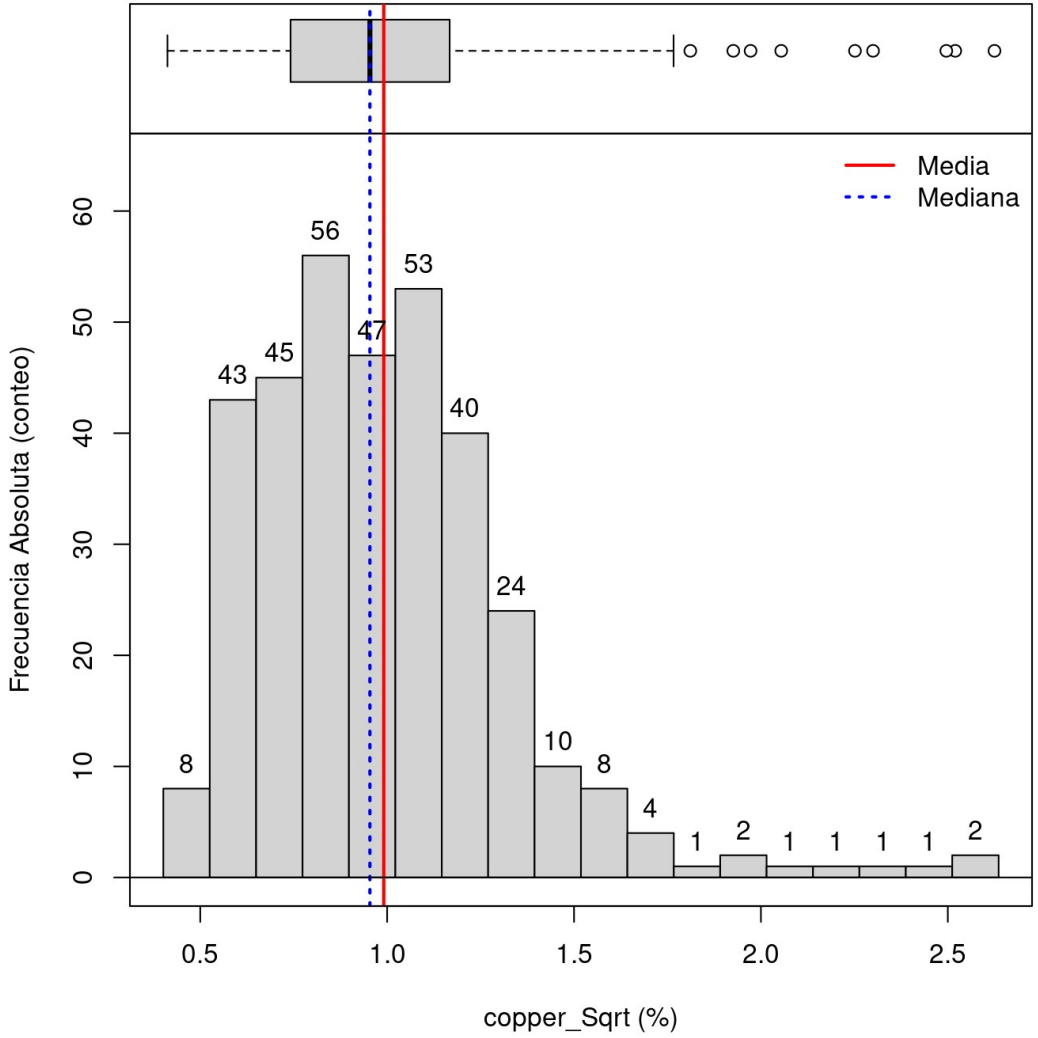
2.1.1 Análisis univariado de cobre



Estadística	Copper_out2. Grade
No_muestras	327
Minimo	0.17
Cuartil_1er	0.5275
Mediana	0.84
Media	0.9381
Cuartil_3er	1.2625
Maximo	2.35
Rango	2.18
Rango_Intercuartil	0.735
Varianza	0.2378
Desv_Estandar	0.4876
Simetria	0.5936
Curtosis	2.5566

2.1.1 Análisis univariado de cobre

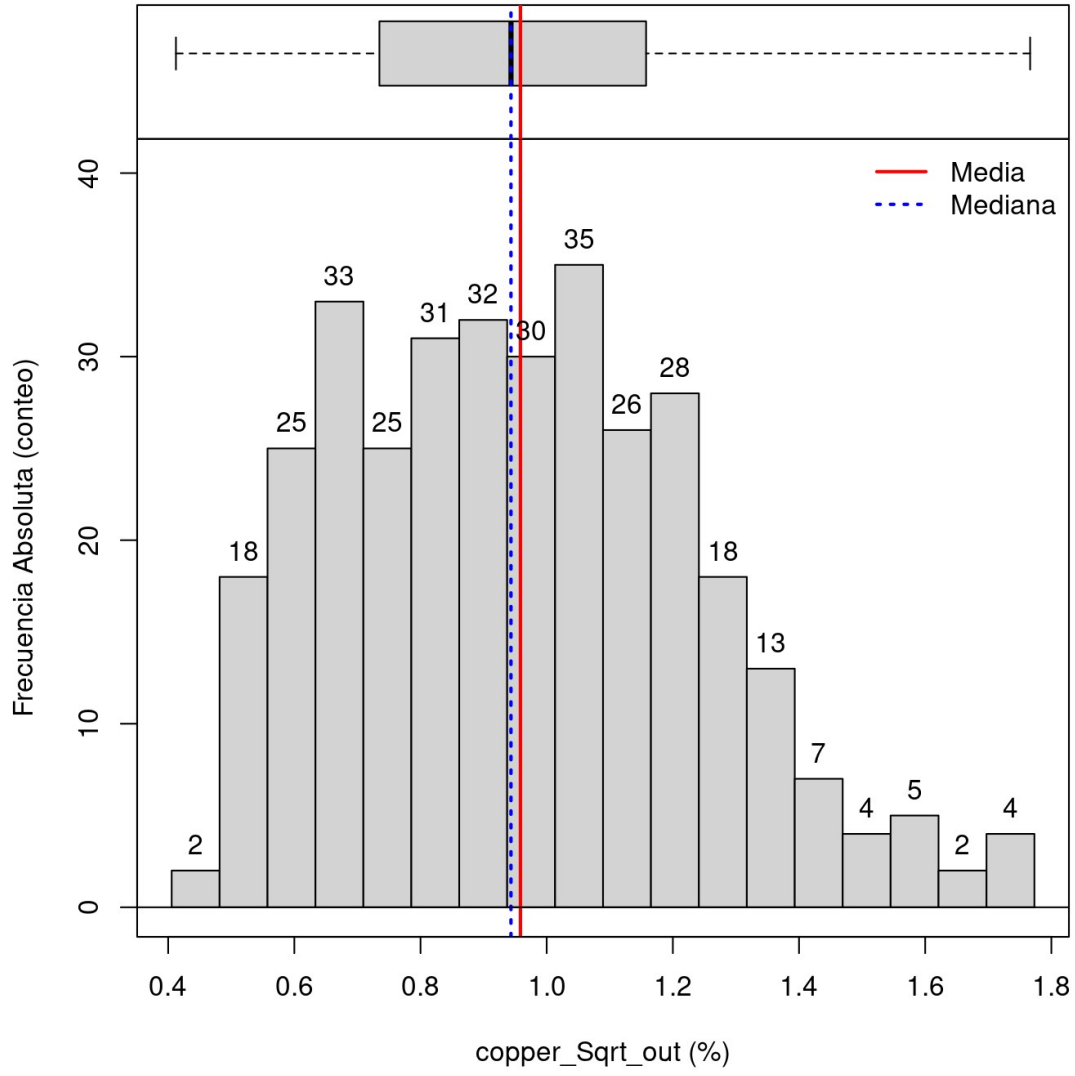
Datos de cobre transformados: Raíz cuadrada



Estadística	Copper_Sqrt. Grade
No_muestras	347
Minimo	0.4123
Cuartil_1er	0.7416
Mediana	0.9539
Media	0.991
Cuartil_3er	1.1673
Maximo	2.6249
Rango	2.2126
Rango_Intercuartil	0.4256
Varianza	0.1184
Desv_Estandar	0.3441
Simetria	1.3951
Curtosis	6.5932

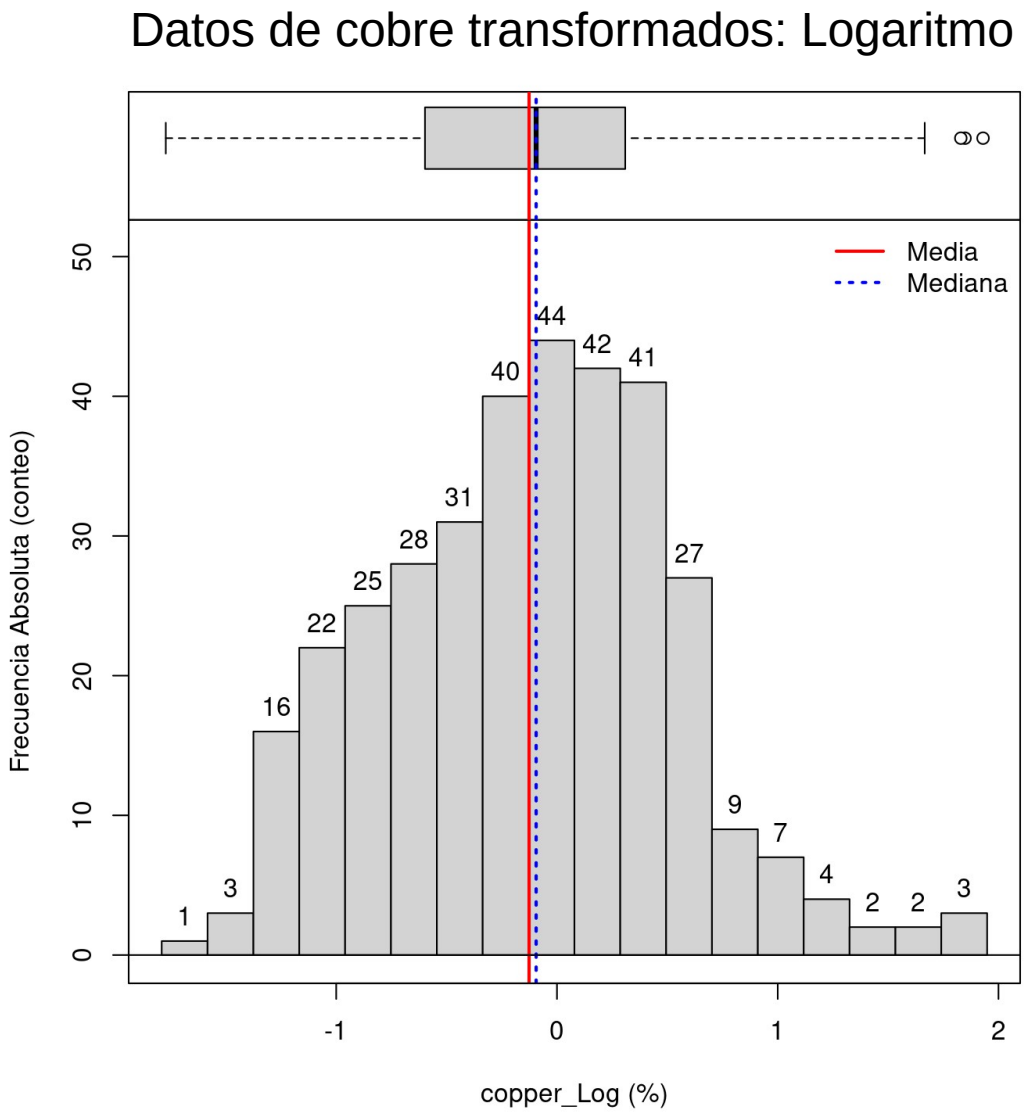
2.1.1 Análisis univariado de cobre

Datos de cobre transformados: Raíz cuadrada y sin outliers



Estadística	Copper_Sqrt_out. Grade
No_muestras	338
Minimo	0.4123
Cuartil_1er	0.7365
Mediana	0.9434
Media	0.9584
Cuartil_3er	1.1576
Maximo	1.7664
Rango	1.354
Rango_Intercuartil	0.421
Varianza	0.0784
Desv_Estandar	0.2799
Simetria	0.4254
Curtosis	2.689

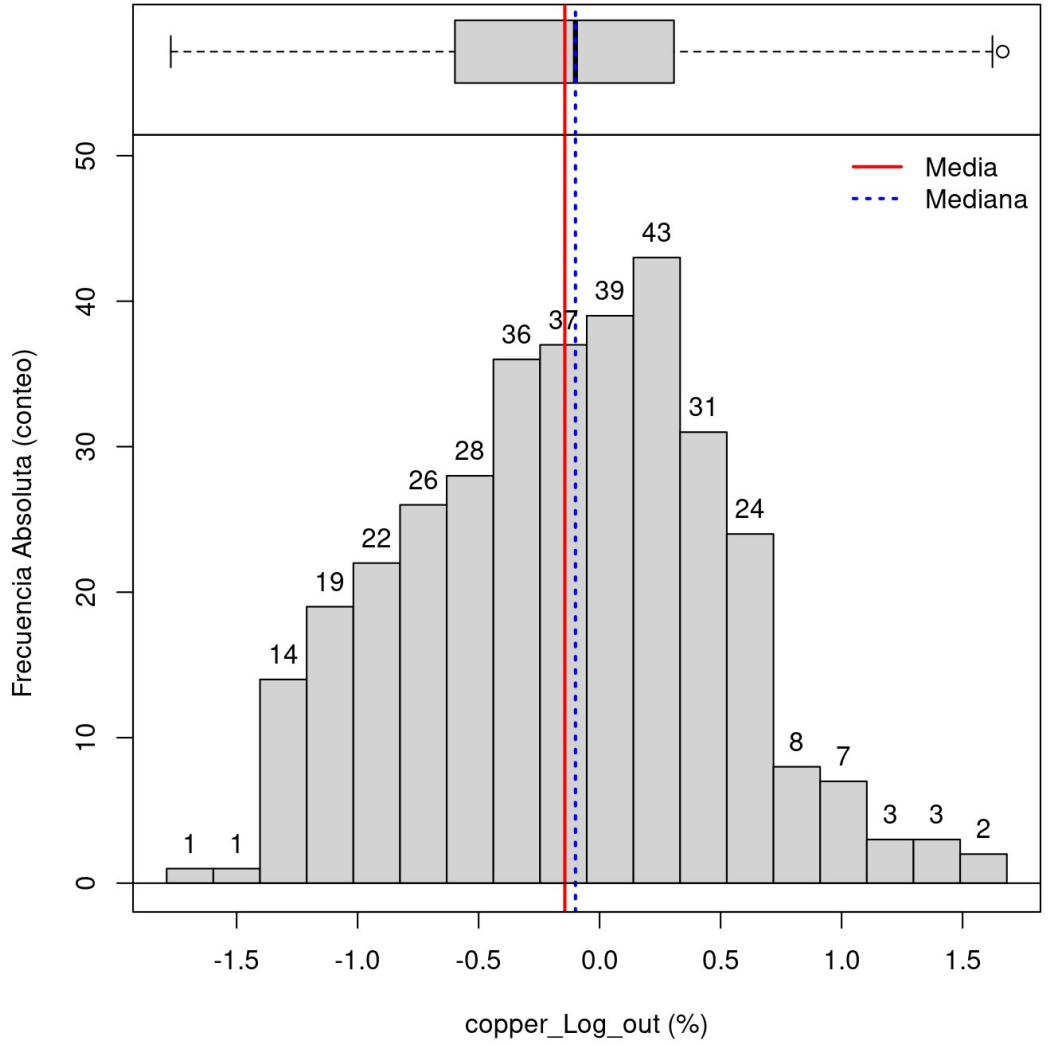
2.1.1 Análisis univariado de cobre



Estadística	Copper_Log.Grade
No_muestras	347
Minimo	-1.772
Cuartil_1er	-0.5978
Mediana	-0.0943
Media	-0.1263
Cuartil_3er	0.3093
Maximo	1.9301
Rango	3.702
Rango_Intercuartil	0.9072
Varianza	0.4255
Desv_Estandar	0.6523
Simetria	0.1941
Curtosis	3.0172

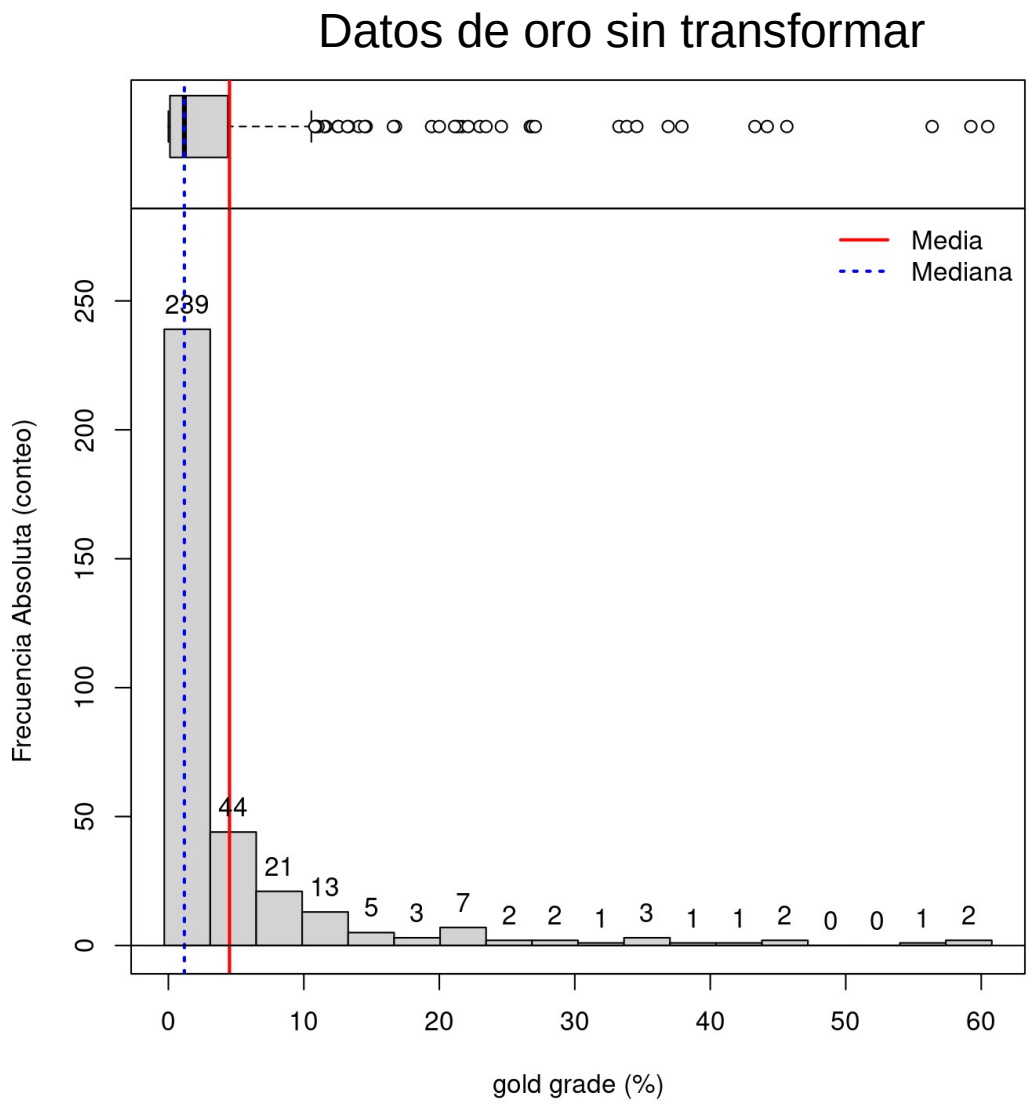
2.1.1 Análisis univariado de cobre

Datos de cobre transformados: Logaritmo y sin outliers



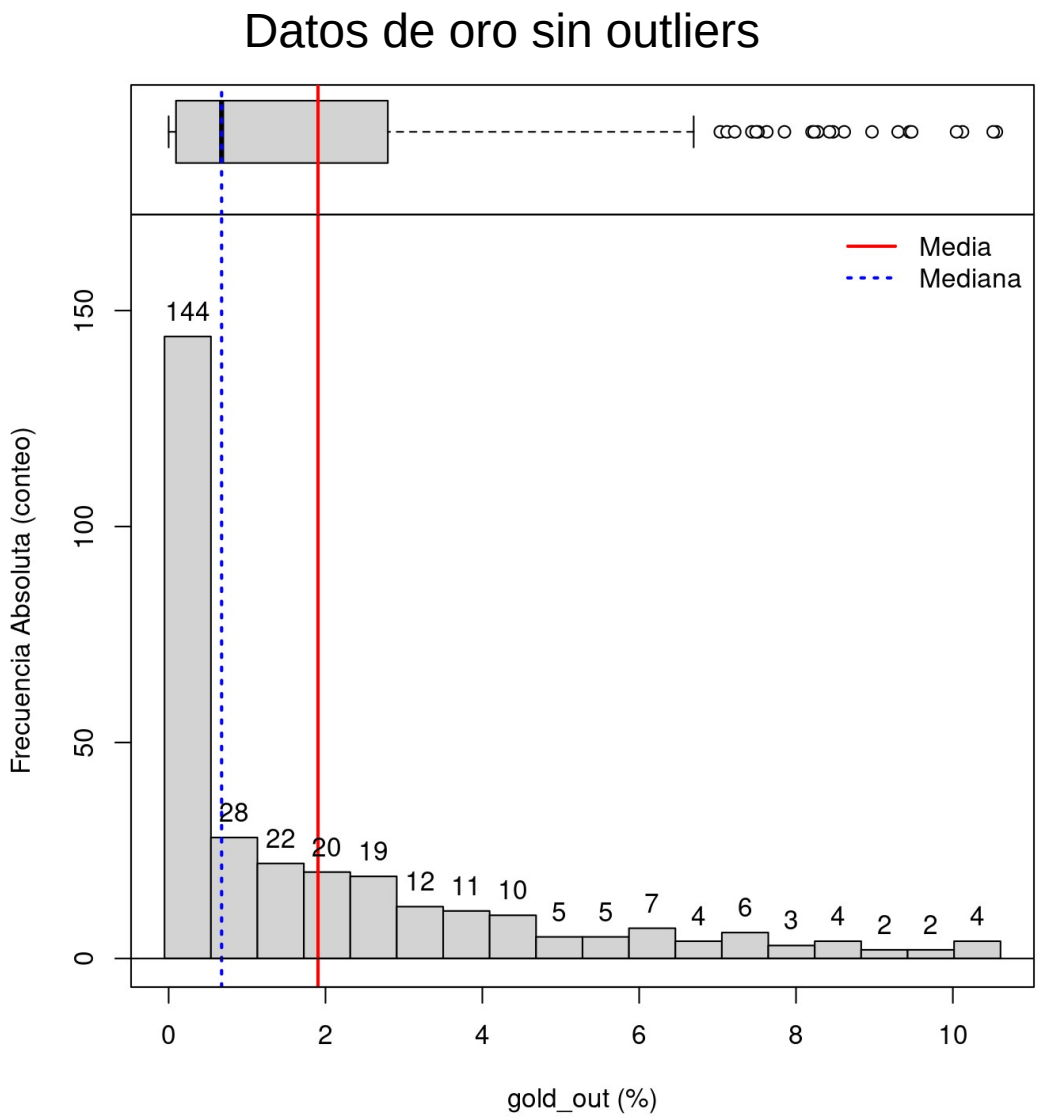
Estadística	Copper_Log_out. Grade
No_muestras	344
Minimo	-1.772
Cuartil_1er	-0.5978
Mediana	-0.0998
Media	-0.1437
Cuartil_3er	0.3075
Maximo	1.6658
Rango	3.4378
Rango_Intercuartil	0.9053
Varianza	0.394
Desv_Estandar	0.6277
Simetria	0.0212
Curtosis	2.6476

2.1.2 Análisis univariado de oro



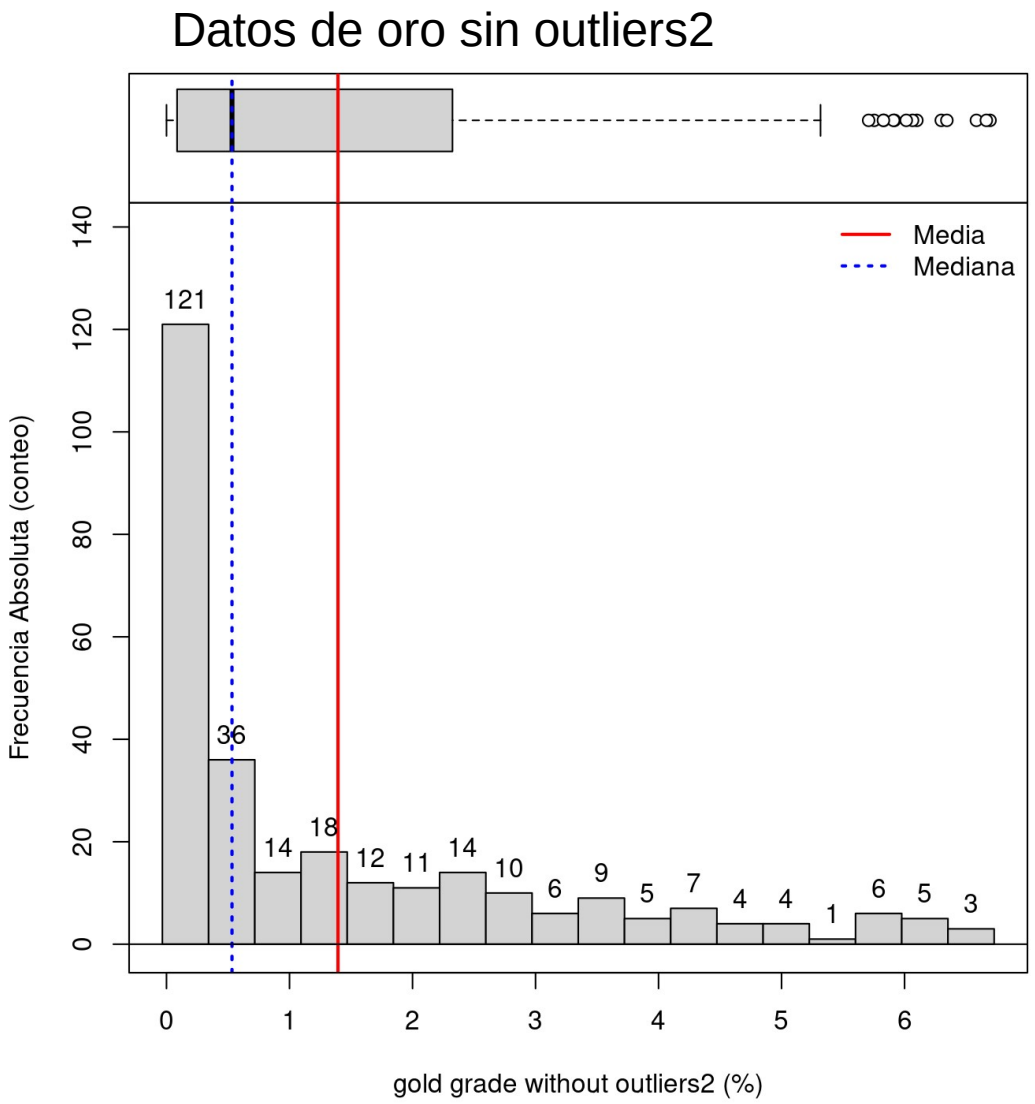
Estadística	gold.Grade
No_muestras	347
Minimo	0.0001
Cuartil_1er	0.1185
Mediana	1.1825
Media	4.5129
Cuartil_3er	4.3893
Maximo	60.479
Rango	60.4789
Rango_Intercuartil	4.2708
Varianza	80.9684
Desv_Estandar	8.9982
Simetria	3.578
Curtosis	17.7141

2.1.2 Análisis univariado de oro



Estadística	gold_out.Grade
No_muestras	308
Minimo	0.0001
Cuartil_1er	0.0948
Mediana	0.6755
Media	1.9047
Cuartil_3er	2.7765
Maximo	10.555
Rango	10.5549
Rango_Intercuartil	2.6818
Varianza	6.2857
Desv_Estandar	2.5071
Simetria	1.5806
Curtosis	4.7398

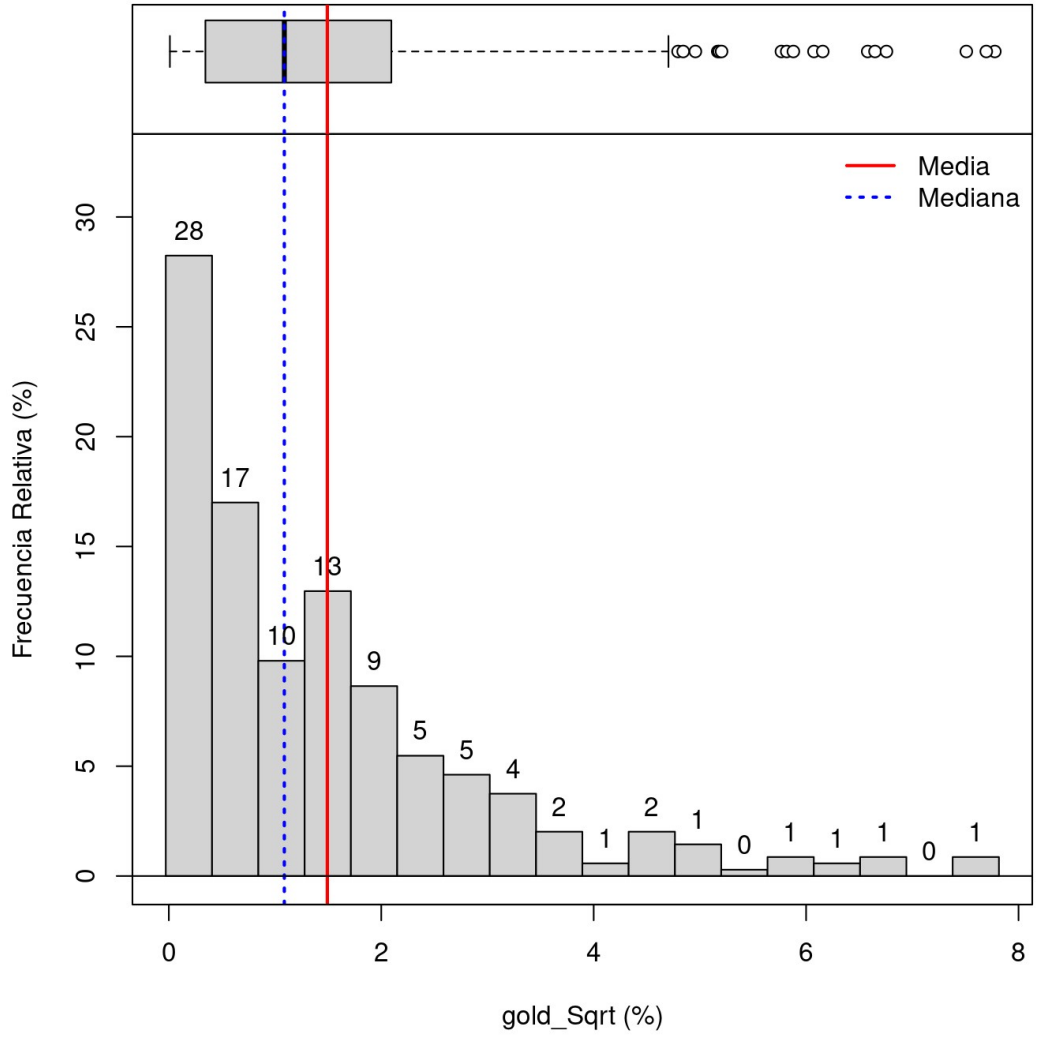
2.1.2 Análisis univariado de oro



Estadística	gold_out.Grade
No_muestras	286
Minimo	0.0001
Cuartil_1er	0.0865
Mediana	0.5325
Media	1.3941
Cuartil_3er	2.3145
Maximo	6.695
Rango	6.6949
Rango_Intercuartil	2.228
Varianza	3.0151
Desv_Estandar	1.7364
Simetria	1.355
Curtosis	3.8835

2.1.2 Análisis univariado de oro

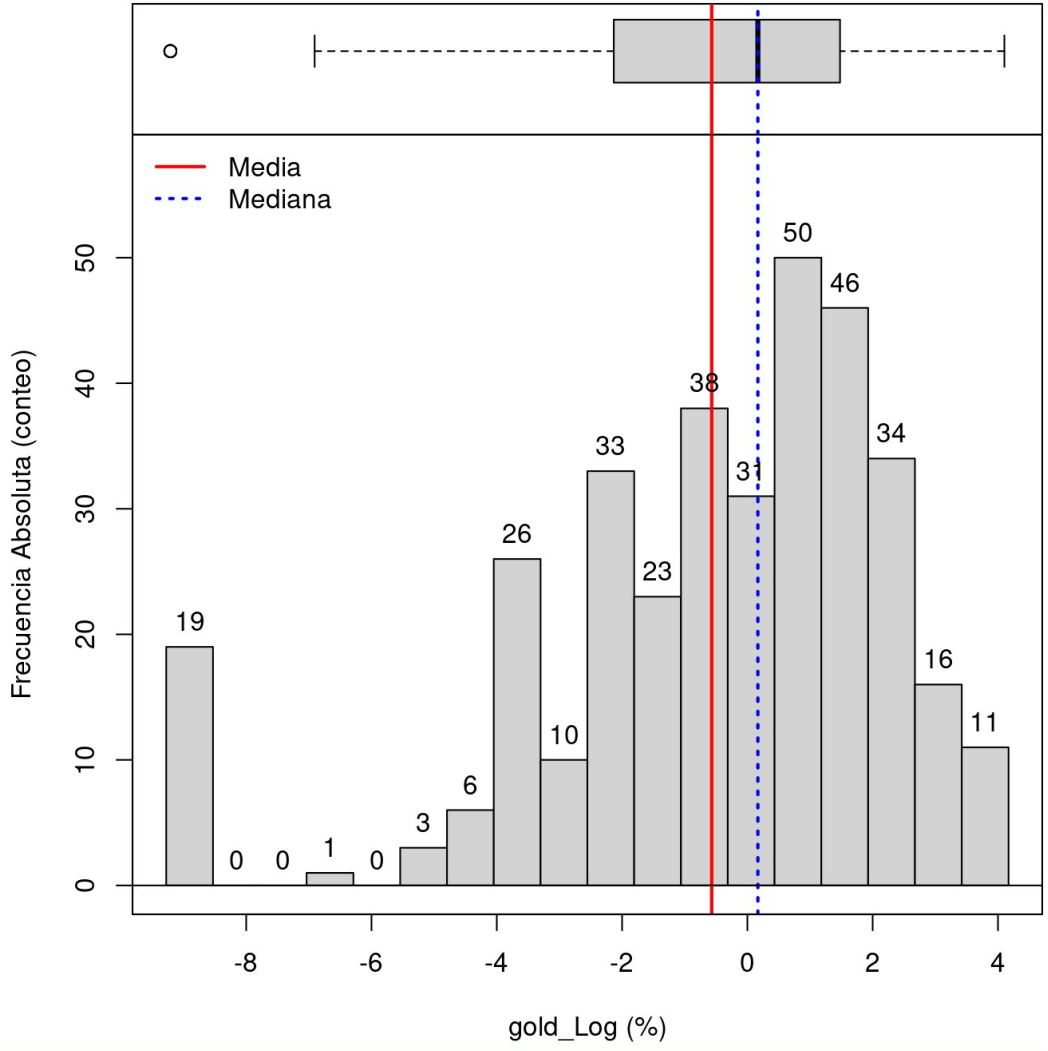
Datos de oro transformado: Raíz cuadrada



Estadística	gold_Sqrt.Grade
No_muestras	347
Minimo	0.01
Cuartil_1er	0.3442
Mediana	1.0874
Media	1.4924
Cuartil_3er	2.095
Maximo	7.7768
Rango	7.7668
Rango_Intercuartil	1.7508
Varianza	2.2922
Desv_Estandar	1.514
Simetria	1.667
Curtosis	5.974

2.1.2 Análisis univariado de oro

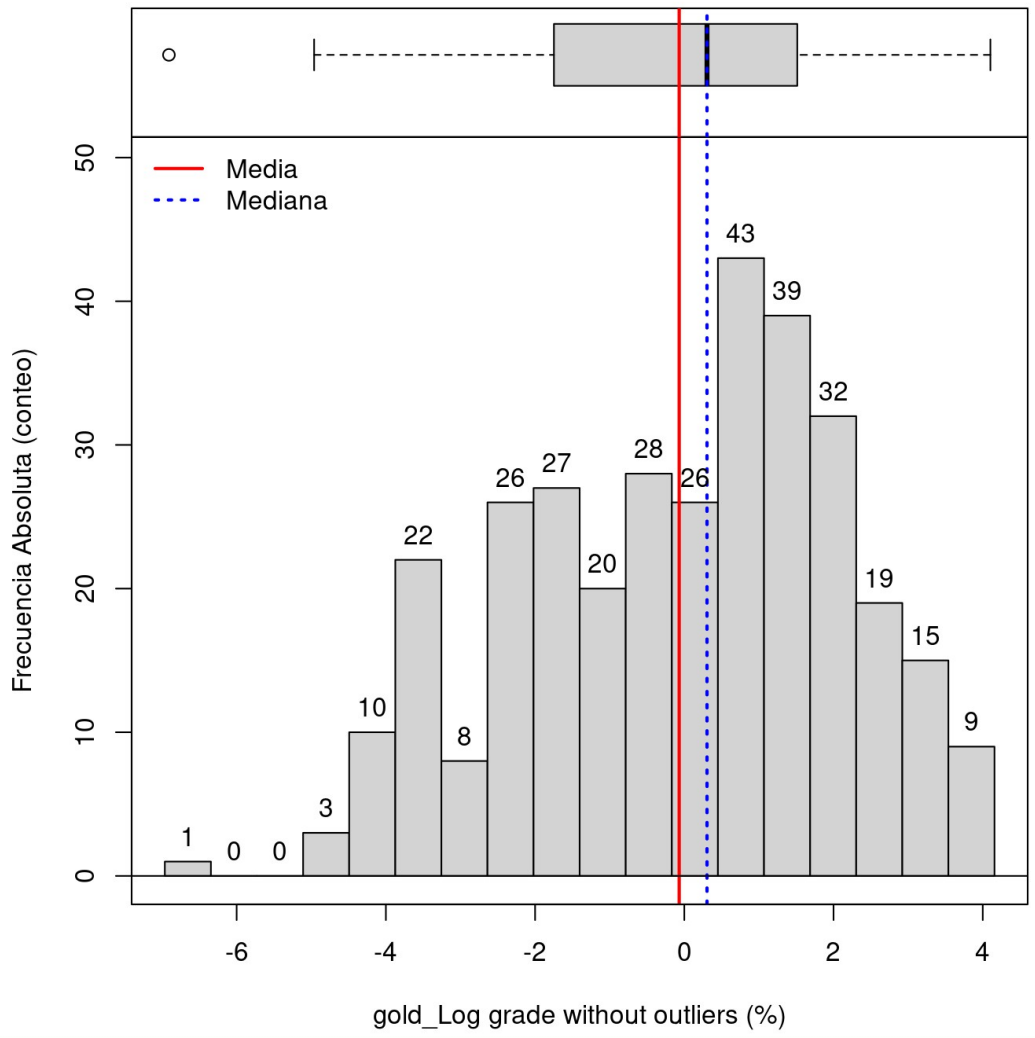
Datos de oro transformado: Logaritmo



Estadística	gold_Log.Grade
No_muestras	347
Minimo	-9.2103
Cuartil_1er	-2.1329
Mediana	0.1676
Media	-0.5691
Cuartil_3er	1.4791
Maximo	4.1023
Rango	13.3126
Rango_Intercuartil	3.6121
Varianza	8.7446
Desv_Estandar	2.9571
Simetria	-1.2408
Curtosis	4.6607

2.1.2 Análisis univariado de oro

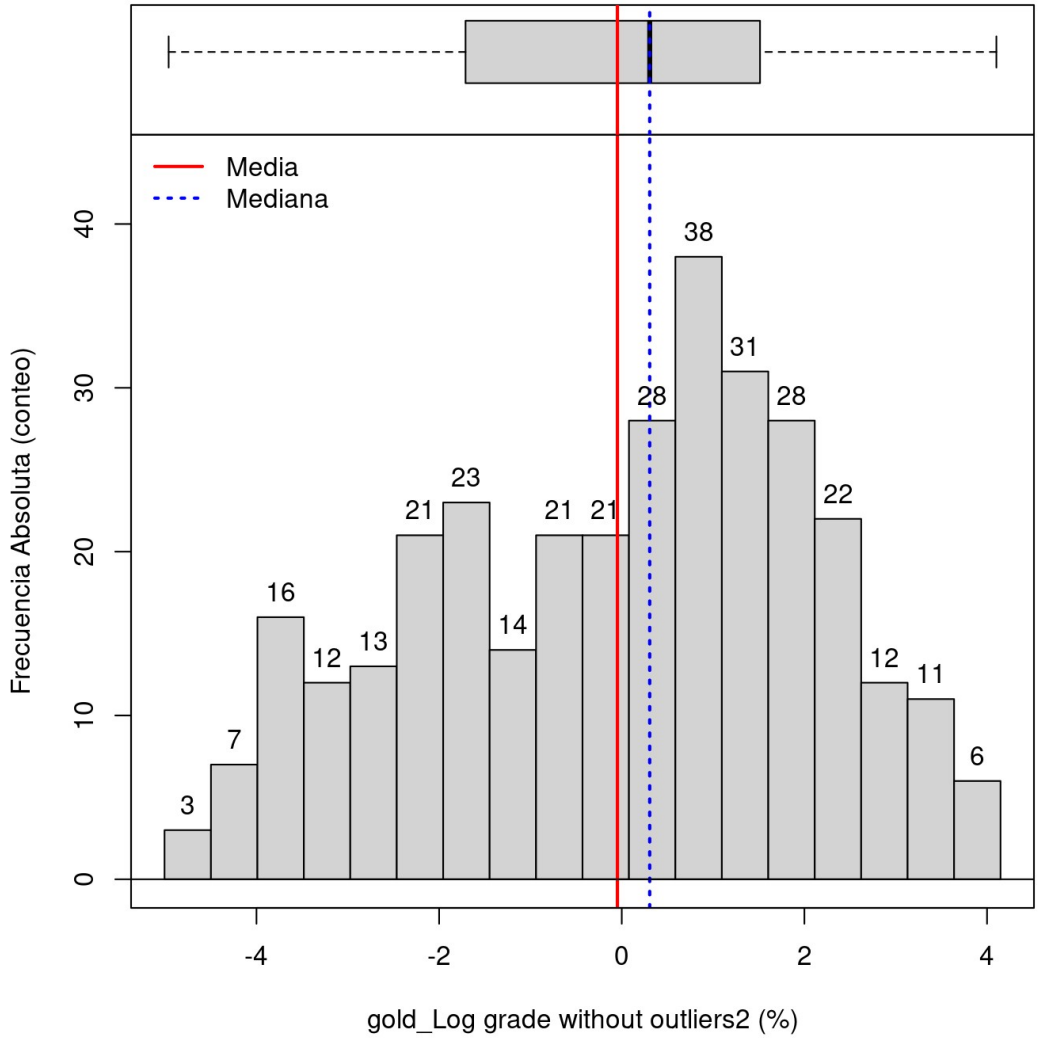
Datos de oro transformado: Logaritmo y sin outliers



Estadística	gold_Log_out. Grade
No_muestras	328
Minimo	-6.9078
Cuartil_1er	-1.7367
Mediana	0.3042
Media	-0.0686
Cuartil_3er	1.5075
Maximo	4.1023
Rango	11.0101
Rango_Intercuartil	3.2443
Varianza	4.6627
Desv_Estandar	2.1593
Simetria	-0.3518
Curtosis	2.4015

2.1.2 Análisis univariado de oro

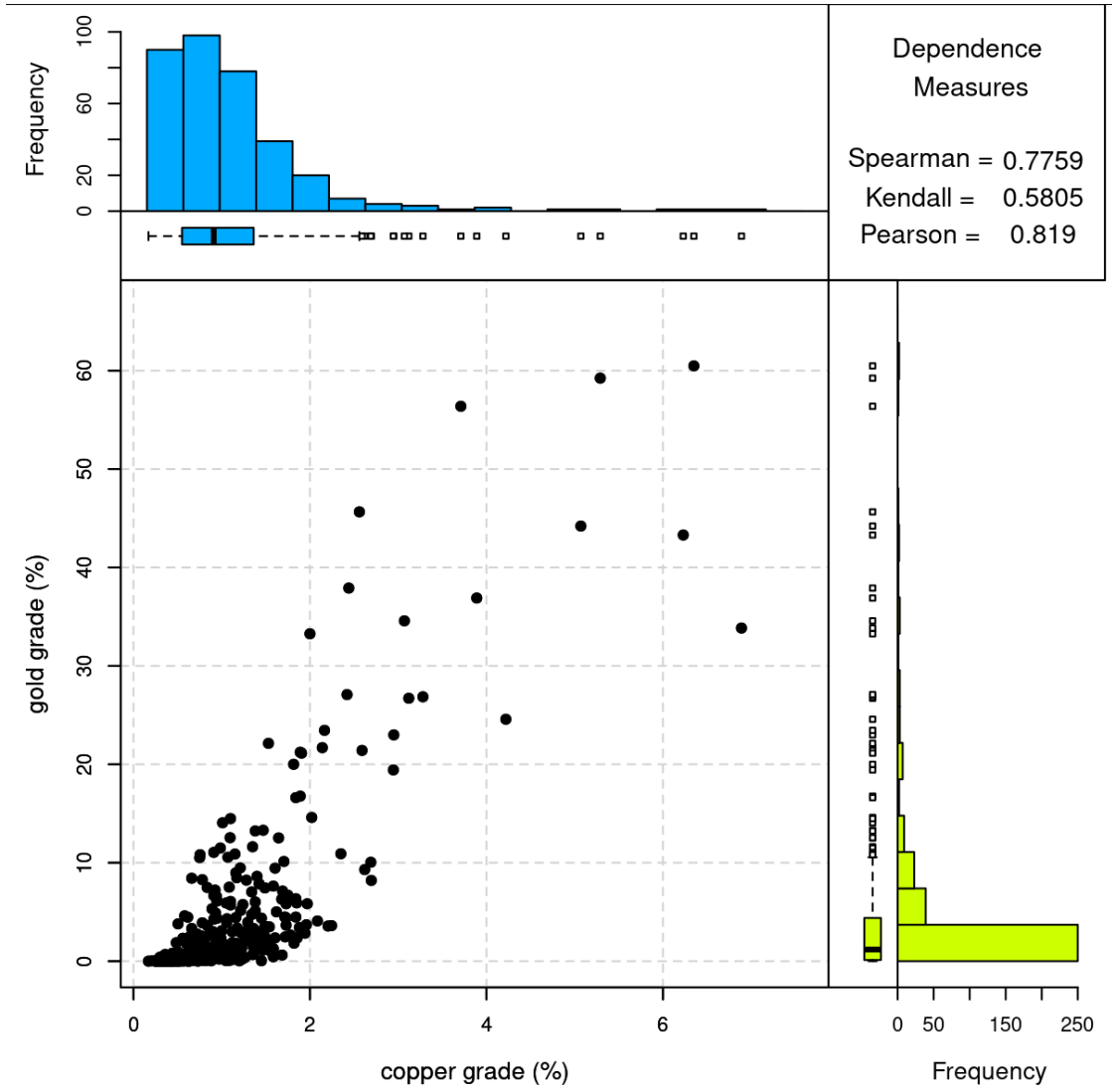
Datos de oro transformado: Logaritmo sin ourliers2



Estadística	gold_Log_out_out. Grade
No_muestras	327
Minimo	-4.9618
Cuartil_1er	-1.7108
Mediana	0.306
Media	-0.0476
Cuartil_3er	1.514
Maximo	4.1023
Rango	9.0641
Rango_Intercuartil	3.2248
Varianza	4.5331
Desv_Estandar	2.1291
Simetria	-0.2958
Curtosis	2.2321

2.2. Análisis bivariado

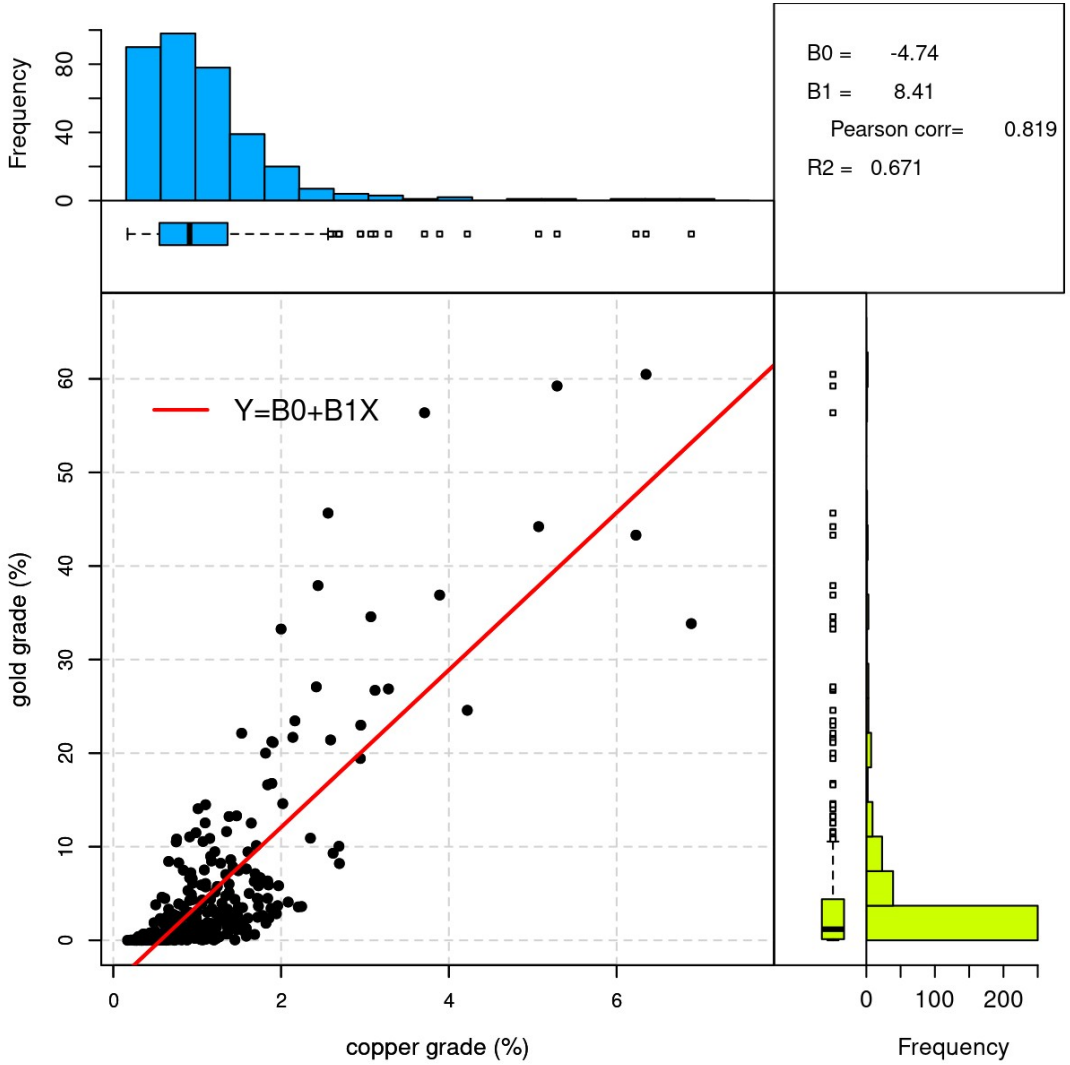
Análisis de dependencia: oro vs. cobre (sin transformar)



Medidas de dependencia	Valor
Spearman	**0.7759**
Kendall	**0.5805**
Pearson	**0.819**

2.2. Análisis bivariado

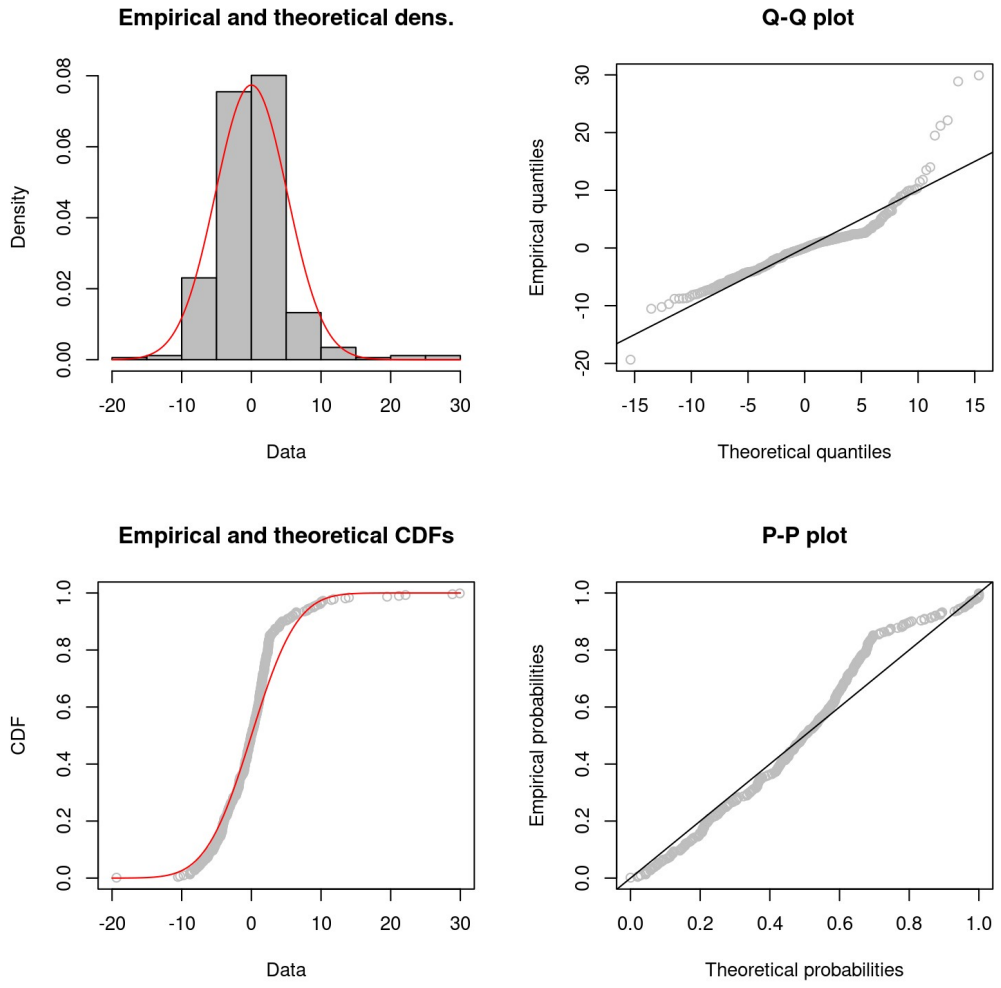
Regresión lineal: oro vs. cobre (sin transformar)



Ecuación lineal	**gold = 8.41 * copper - 4.74**
Pearson	**0.819**
Coeficiente de determinación = Pearson²	**0.671**

2.2. Análisis bivariado

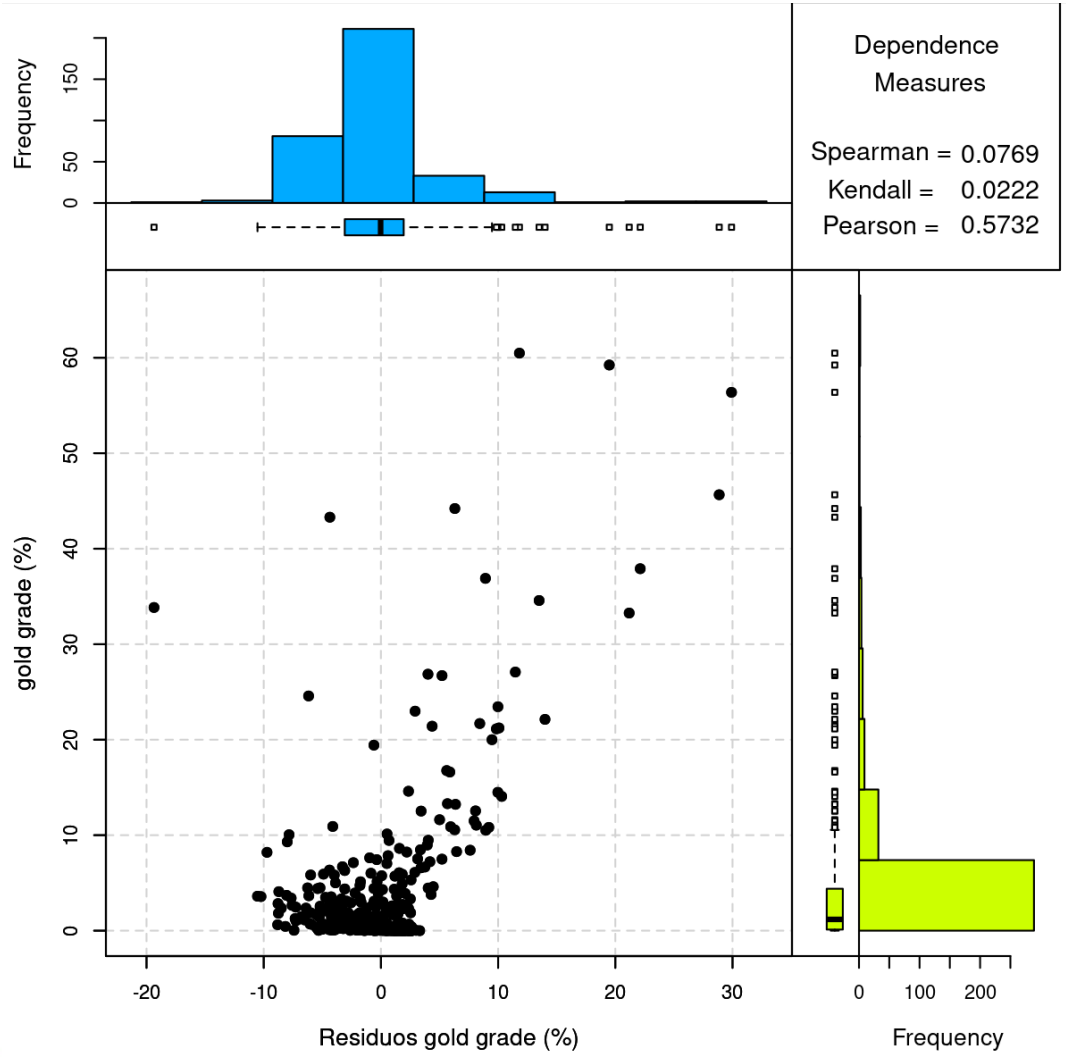
Análisis de residuos de la regresión lineal:
oro vs. cobre (sin transformar)



Estadística	Residuos_gold
No_muestras	347
Minimo	-19.3609
Cuartil_1er	-3.0877
Mediana	-0.0257
Media	-0.0004
Cuartil_3er	1.9427
Maximo	29.9149
Rango	49.2758
Rango_Intercuartil	5.0304
Varianza	26.6536
Desv_Estandar	5.1627
Simetria	1.5683
Curtosis	10.5582

2.2. Análisis bivariado

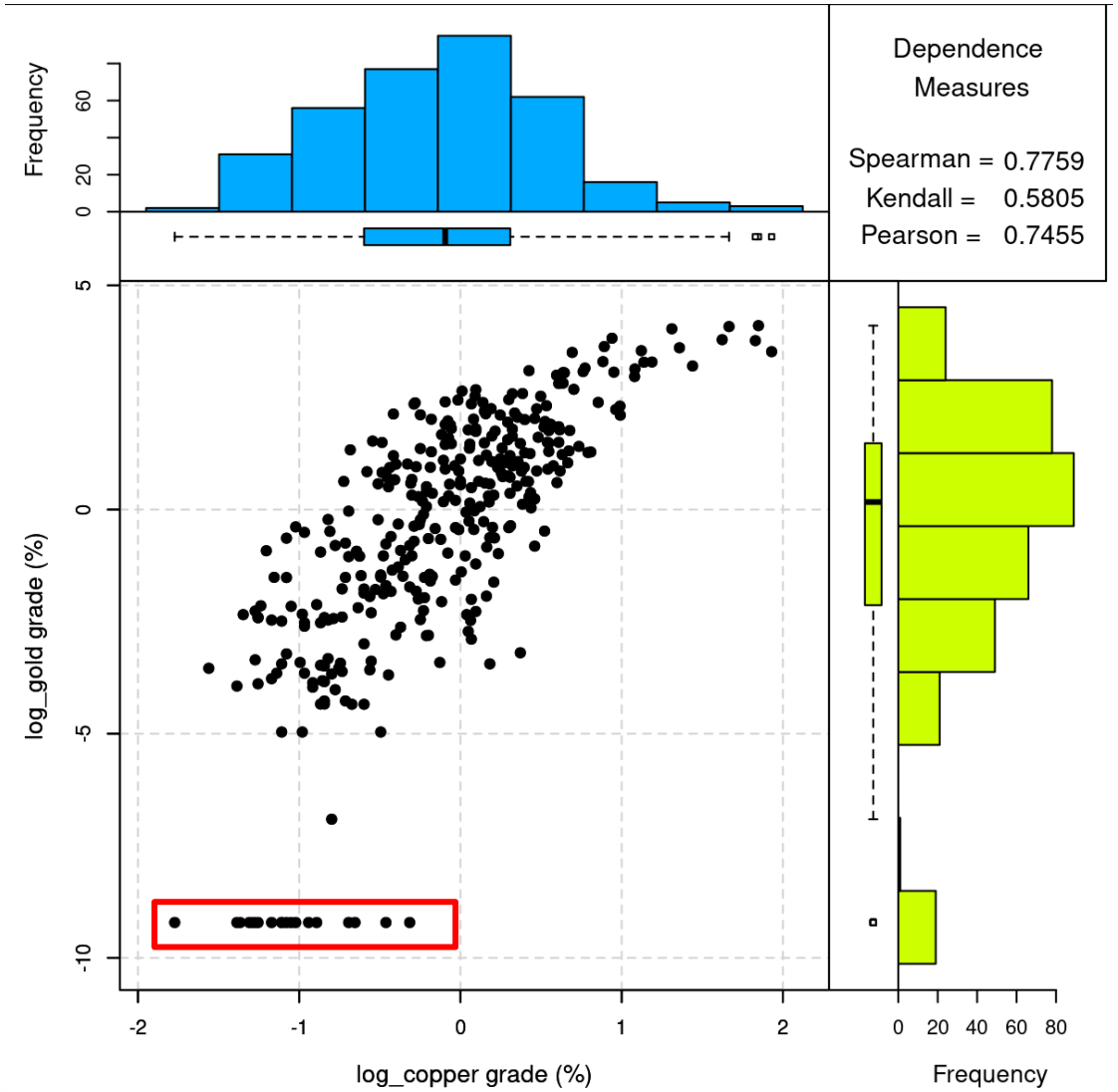
Análisis de residuos de la regresión lineal: oro vs. cobre (sin transformar)



Estadística	Residuos_gold
No_muestras	347
Minimo	-19.3609
Cuartil_1er	-3.0877
Mediana	-0.0257
Media	-0.0004
Cuartil_3er	1.9427
Maximo	29.9149
Rango	49.2758
Rango_Intercuartil	5.0304
Varianza	26.6536
Desv_Estandar	5.1627
Simetria	1.5683
Curtosis	10.5582

2.2. Análisis bivariado

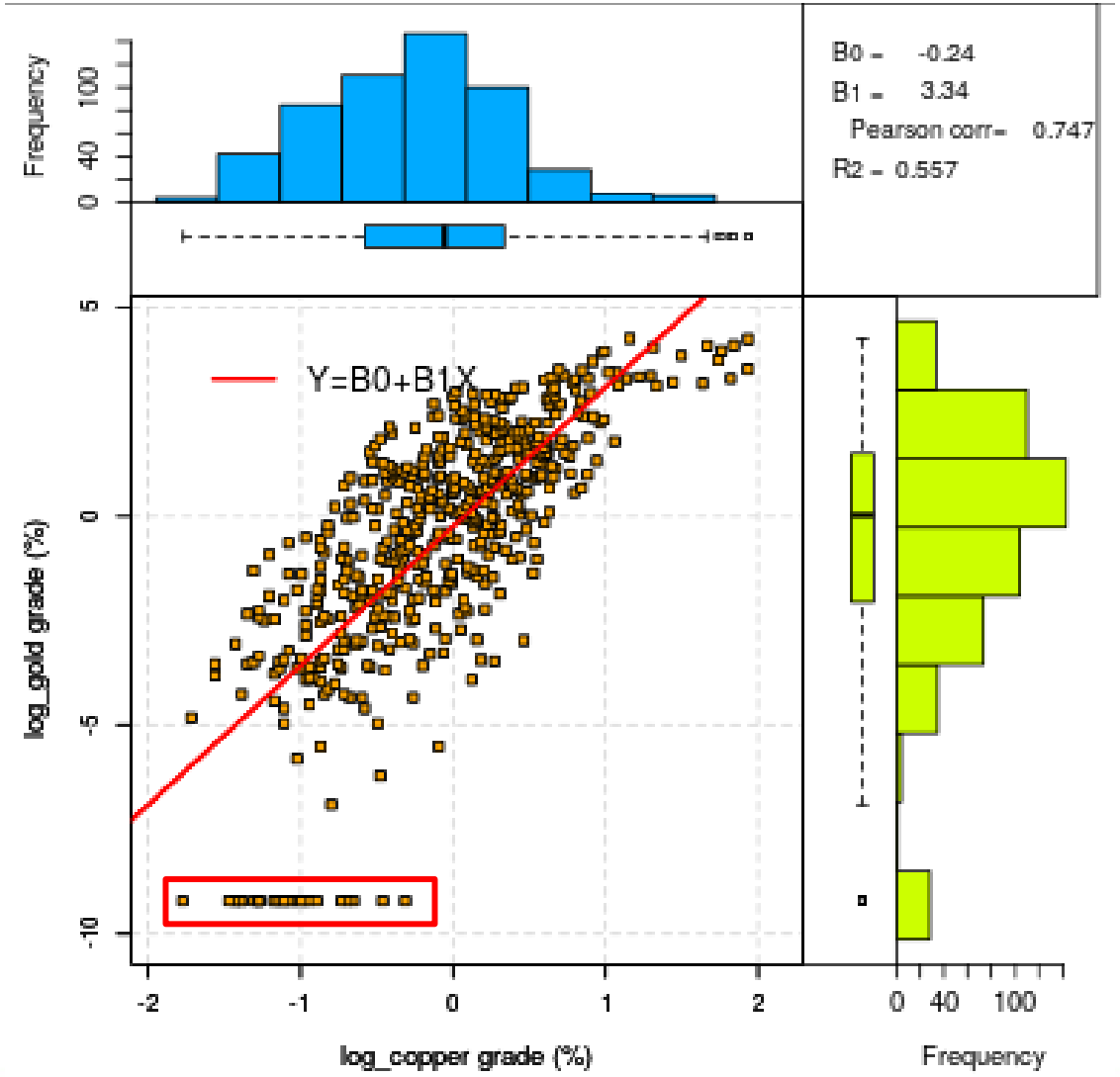
Análisis de dependencia: oro vs. cobre (transformados)



Medidas de dependencia	Valor
Spearman	0.7759
Kendall	0.5805
Pearson	0.7455

2.2. Análisis bivariado

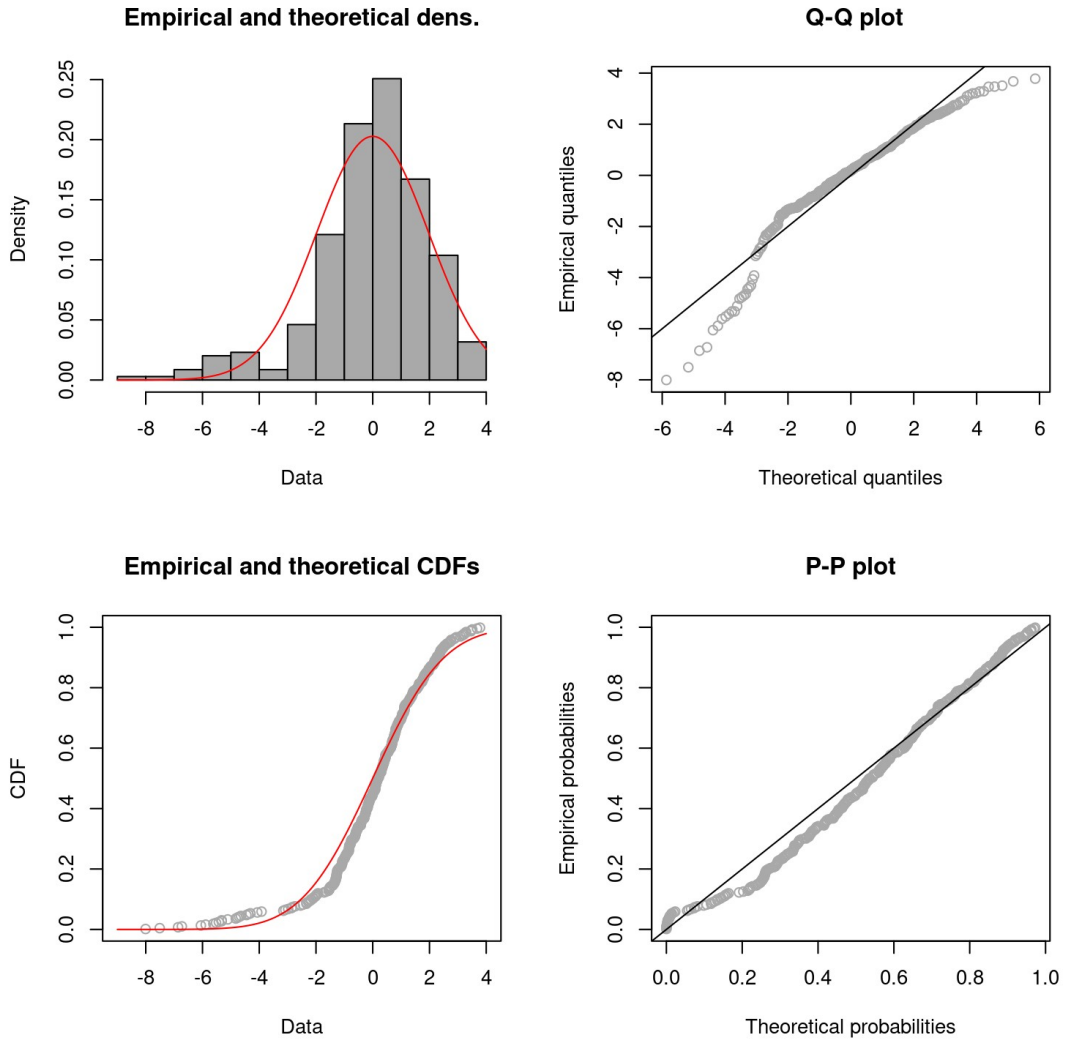
Regresión lineal: oro vs. cobre (transformados)



Ecuación lineal	**log_gold = 3.34 * log_copper -0.24**
Pearson	**0.747**
Coeficiente de determinación	**0.557**

2.2. Análisis bivariado

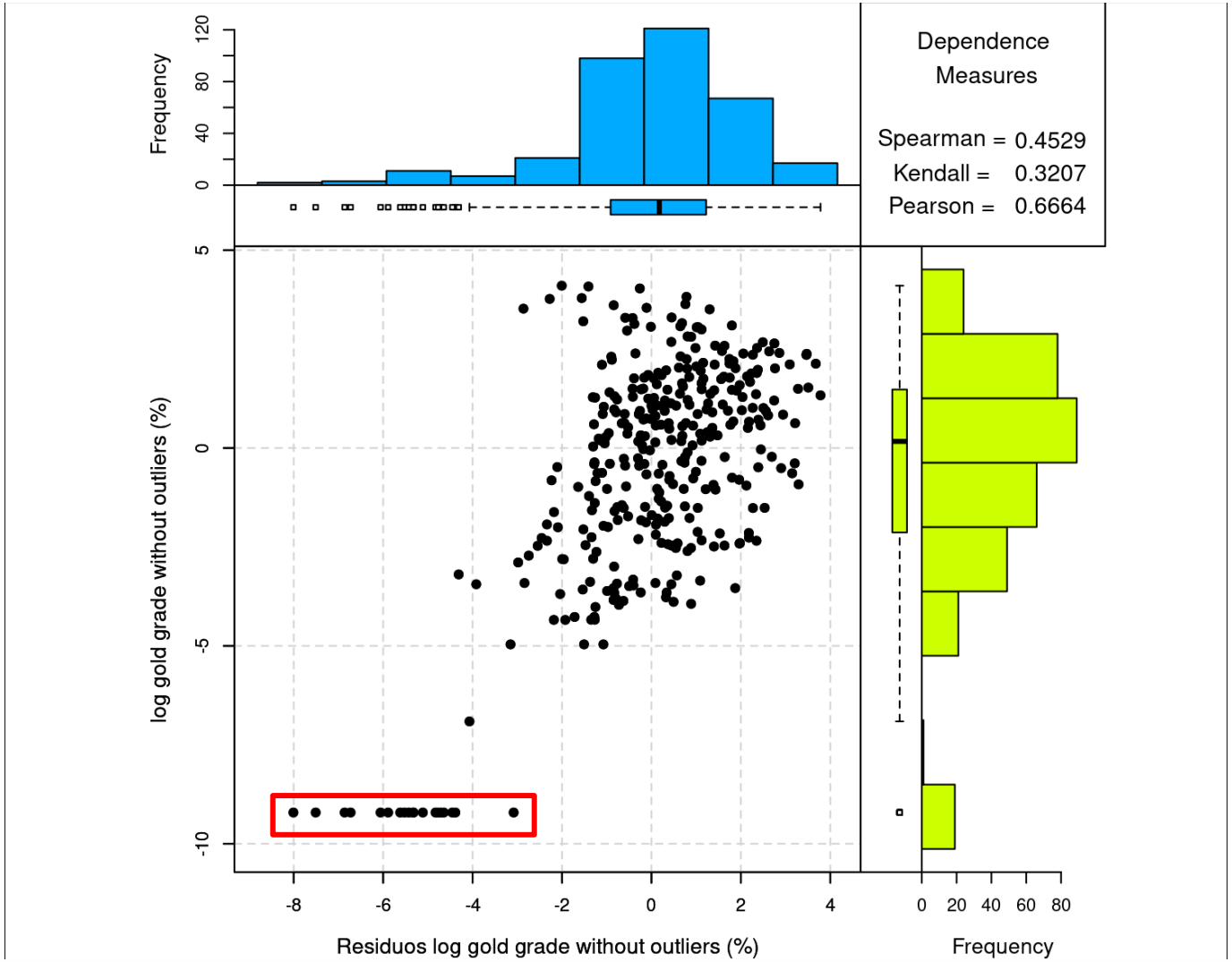
Análisis de residuos de la regresión lineal: oro vs. cobre (transformados)



Estadística	Residuos_ gold_Log
No_muestras	347
Minimo	-8.0066
Cuartil_1er	-0.9135
Mediana	0.1768
Media	-0.0021
Cuartil_3er	1.2238
Maximo	3.781
Rango	11.7877
Rango_Intercuartil	2.1373
Varianza	3.8844
Desv_Estandar	1.9709
Simetria	-1.1255
Curtosis	5.1546

2.2. Análisis bivariado

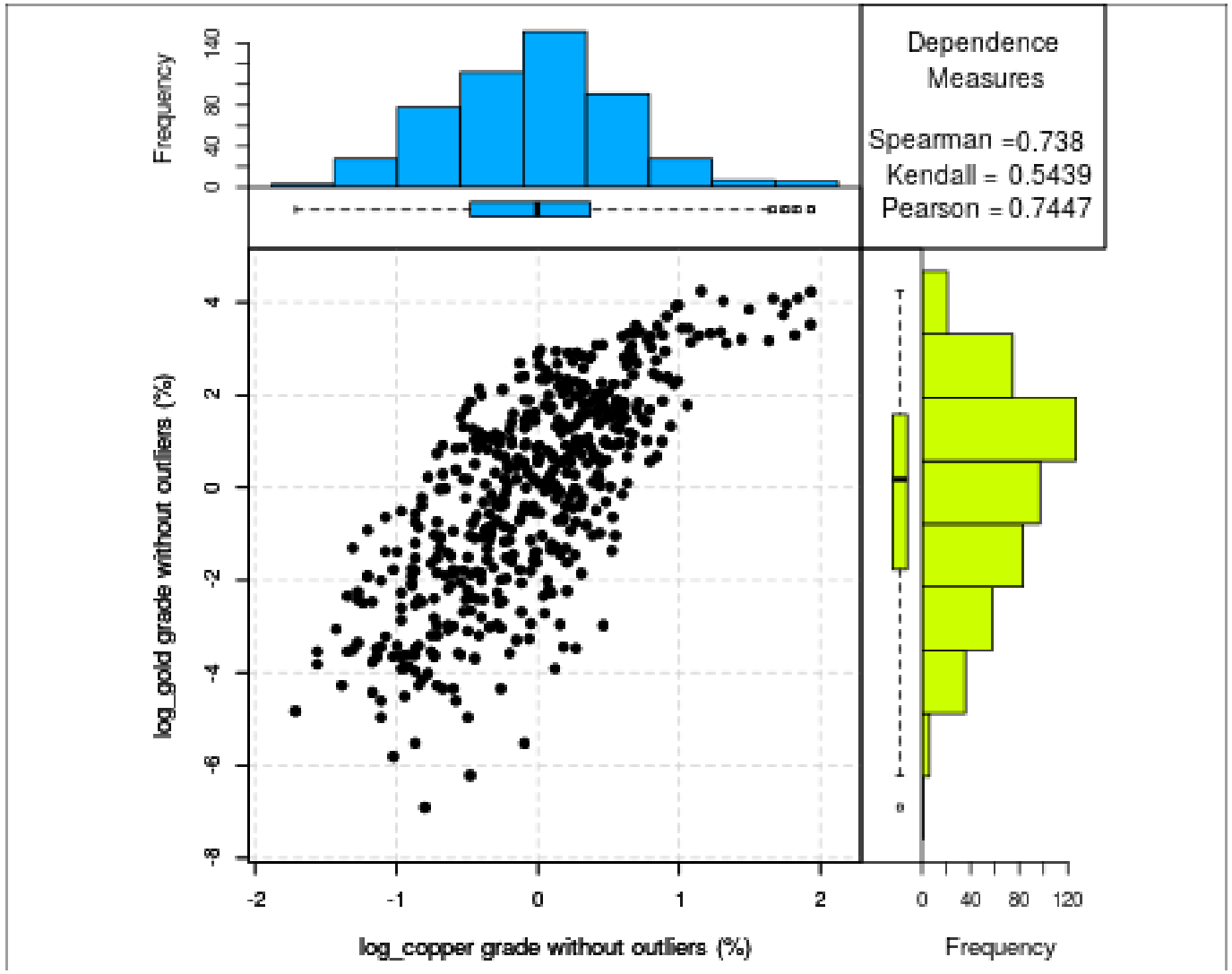
Análisis de residuos de la regresión lineal: oro vs. cobre (transformados)



Estadística	Residuos_ gold_Log
No_muestras	347
Minimo	-8.0066
Cuartil_1er	-0.9135
Mediana	0.1768
Media	-0.0021
Cuartil_3er	1.2238
Maximo	3.781
Rango	11.7877
Rango_Intercuartil	2.1373
Varianza	3.8844
Desv_Estandar	1.9709
Simetria	-1.1255
Curtosis	5.1546

2.2. Análisis bivariado

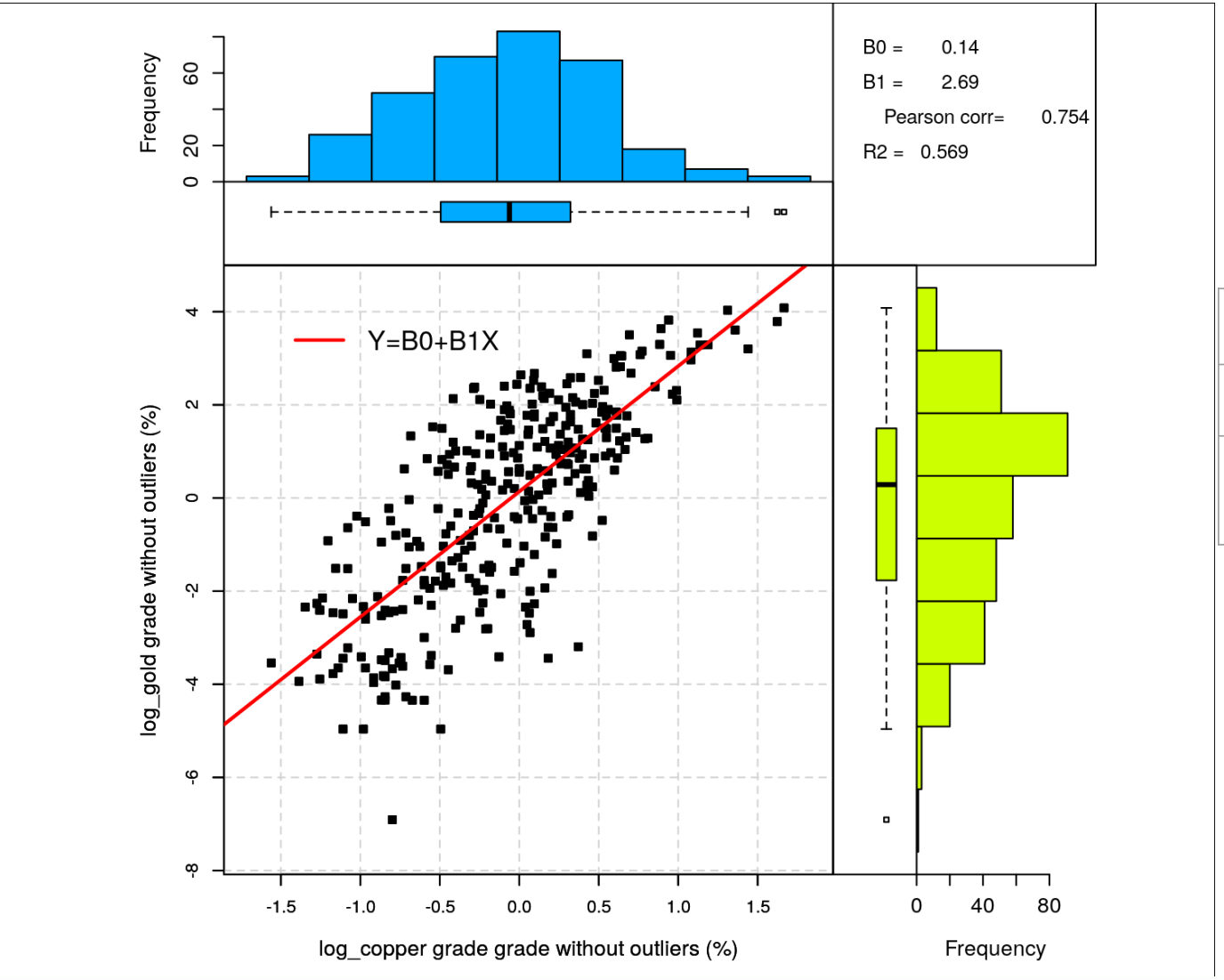
Análisis de dependencia: oro vs. cobre (transformados y sin outliers)



Medidas de dependencia	Valor
Spearman	**0.738**
Kendall	**0.5439**
Pearson	**0.7447**

2.2. Análisis bivariado

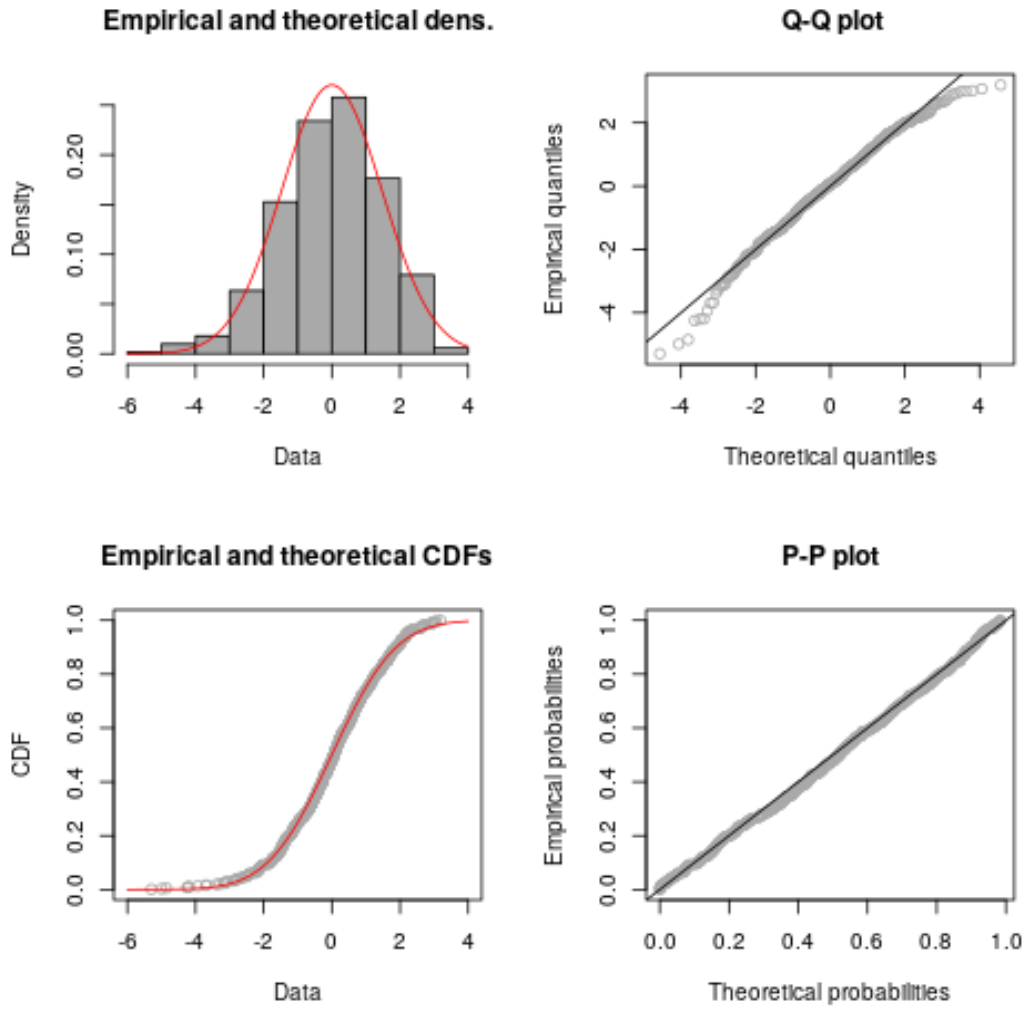
Regresión lineal: oro vs. cobre (transformados y sin outliers)



Ecuación lineal	**log_gold = 2.69 * log_copper + 0.14**
Pearson	**0.754**
Coeficiente de determinación	**0.569**

2.2. Análisis bivariado

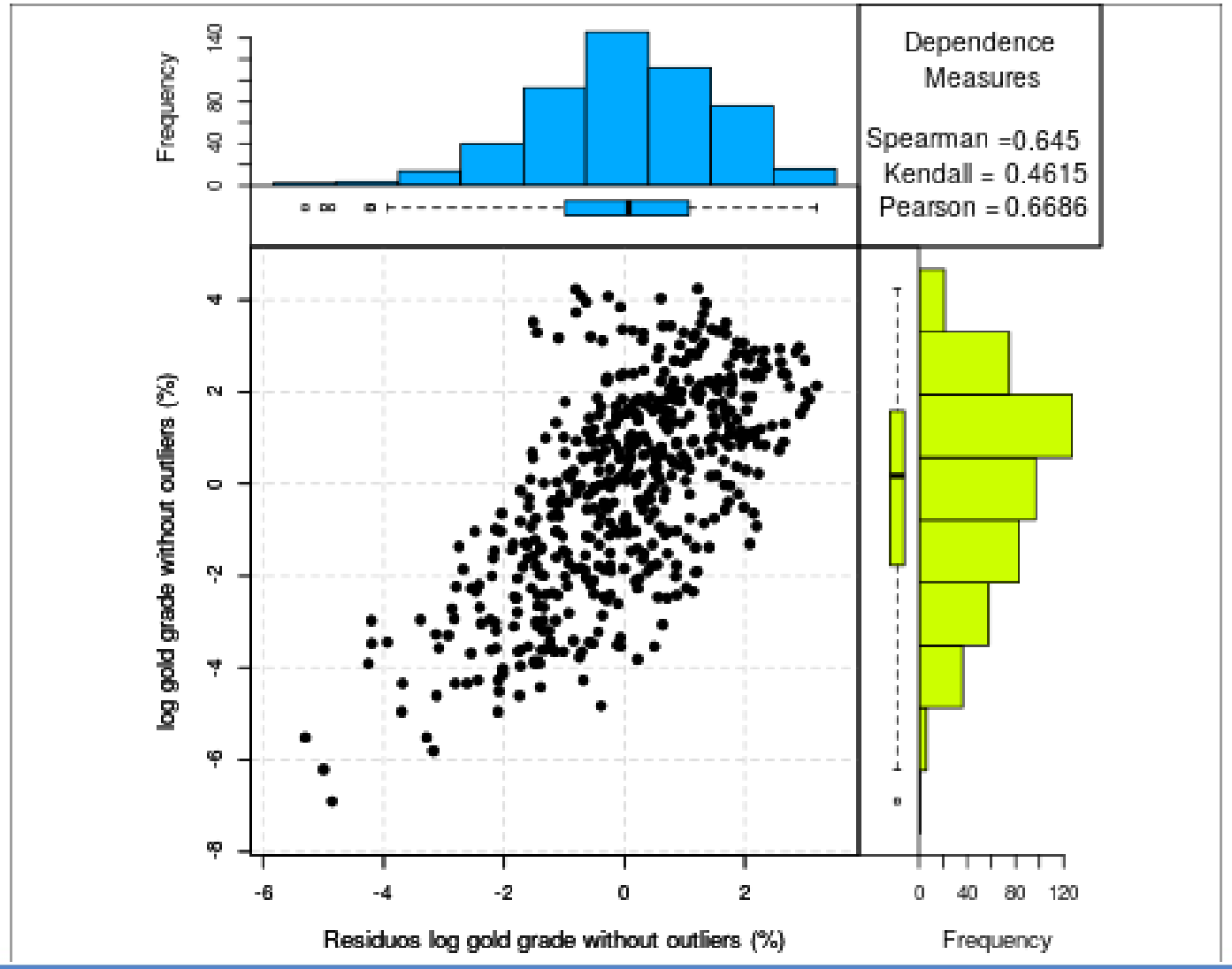
Análisis de residuos de la regresión lineal: oro vs. cobre (transformados y sin outliers)



Estadística	Residuos_gold_Log_out
No_muestras	325
Minimo	-4.8998
Cuartil_1er	-0.8113
Mediana	-0.0169
Media	-0.0017
Cuartil_3er	1.0167
Maximo	3.1091
Rango	8.0088
Rango_Intercuartil	1.828
Varianza	1.9674
Desv_Estandar	1.4026
Simetria	-0.3312
Curtosis	3.1358

2.2. Análisis bivariado

Análisis de residuos de la regresión lineal: oro vs. cobre (transformados y sin outliers)

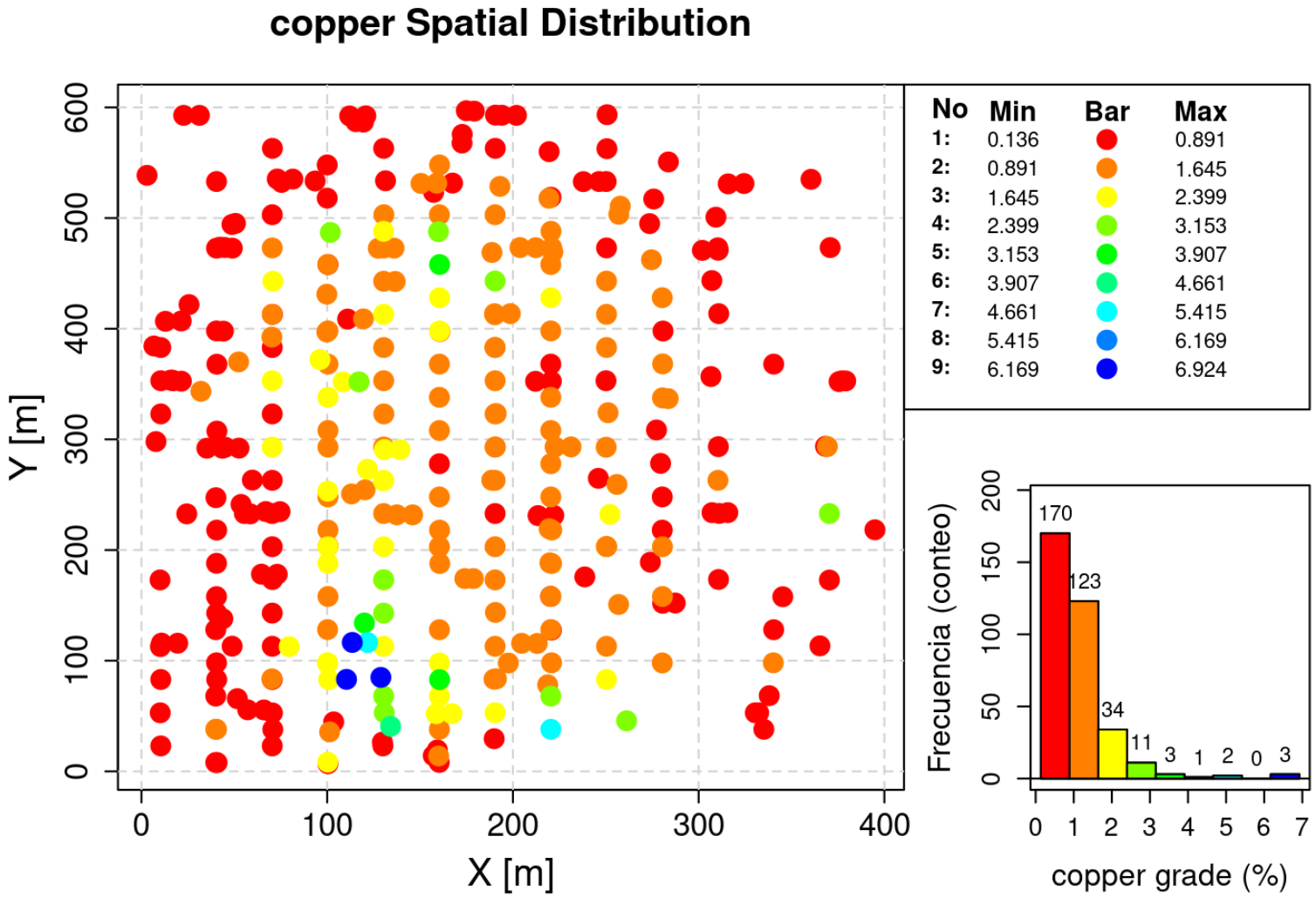


Estadística	Residuos_gold_Log_out
No_muestras	325
Minimo	-4.8998
Cuartil_1er	-0.8113
Mediana	-0.0169
Media	-0.0017
Cuartil_3er	1.0167
Maximo	3.1091
Rango	8.0088
Rango_Intercuartil	1.828
Varianza	1.9674
Desv_Estandar	1.4026
Simetria	-0.3312
Curtosis	3.1358

3. Análisis variográfico

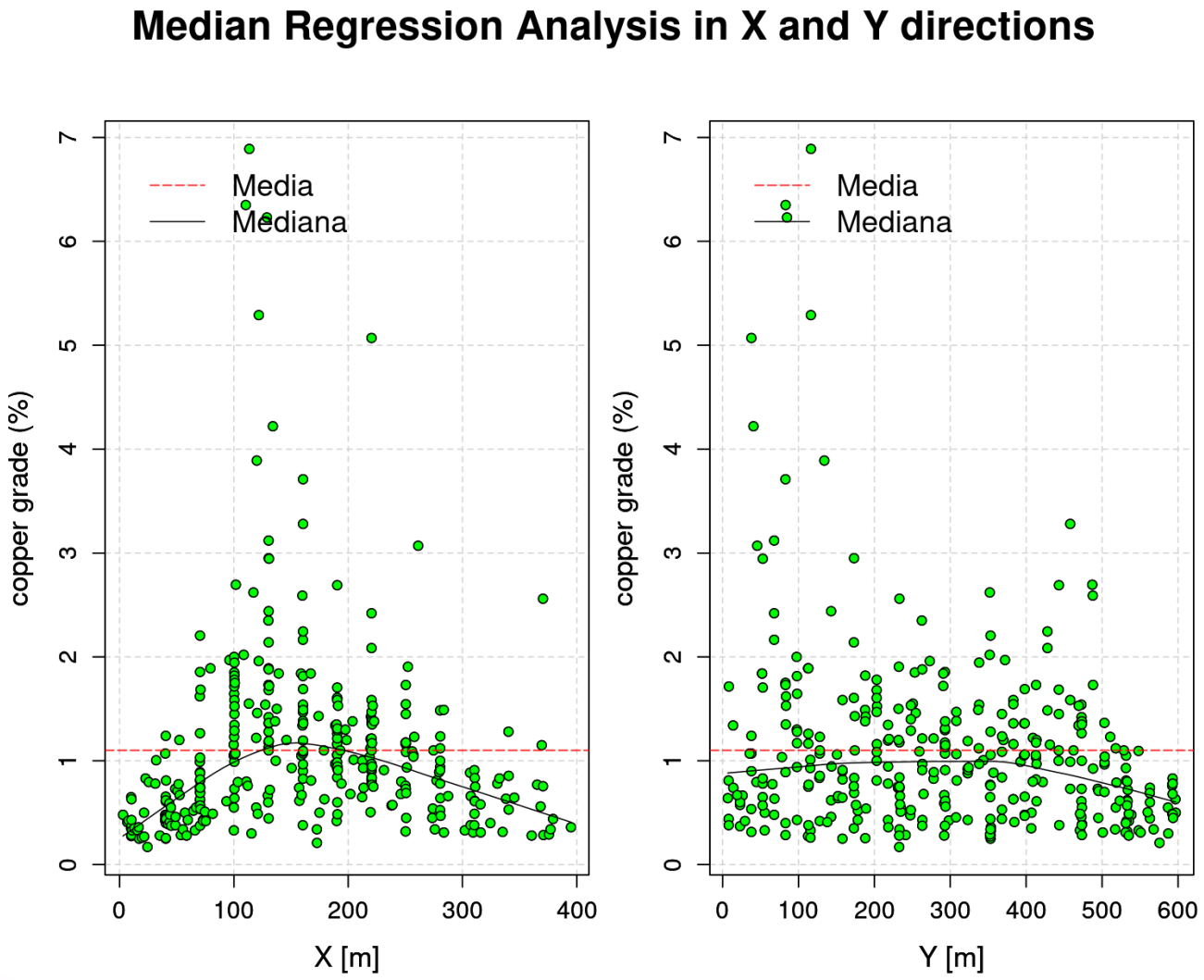
3.1. Análisis de estacionaridad

Datos de cobre sin transformar



3.1. Análisis de estacionaridad

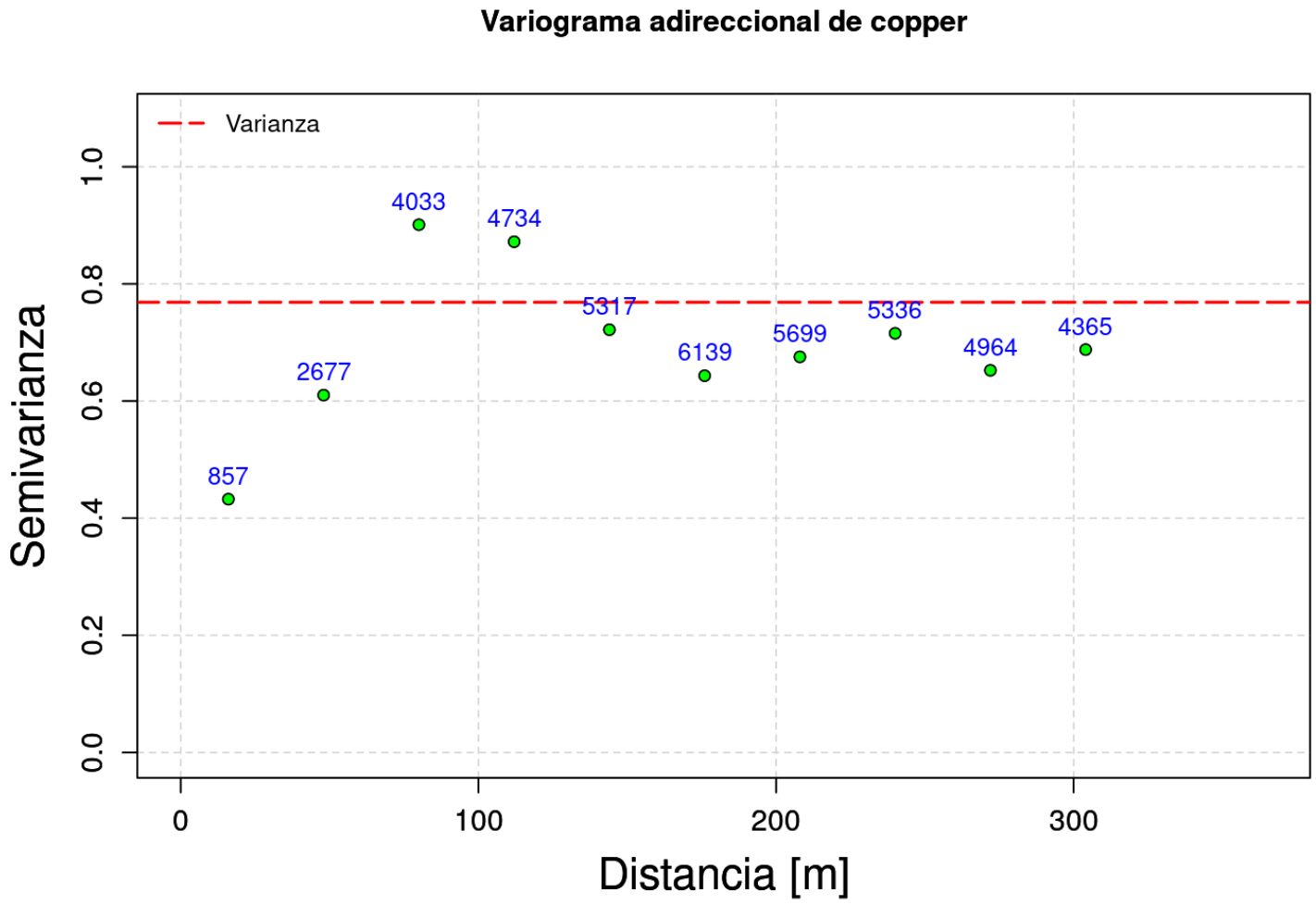
Datos de cobre sin transformar



3.1. Análisis de estacionaridad

N_lags = 10
DistMin = 0.1 m
DistMax = 636.7078 m
lag_value = max((DistMax/2)/N_lags
= 32 m (aproximadamente)

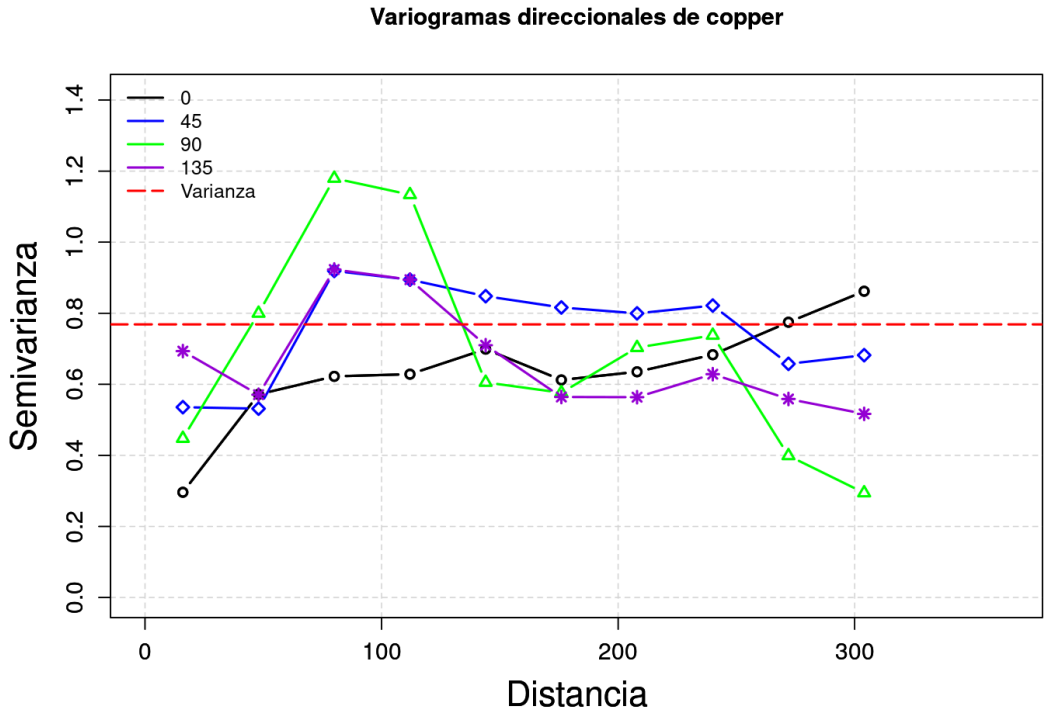
Datos de cobre sin transformar

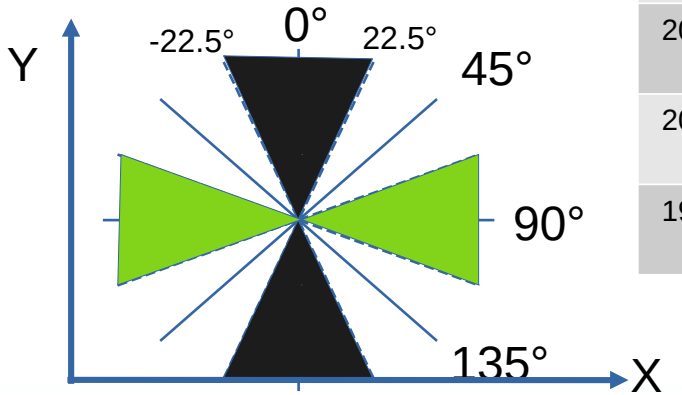


Npares	Lags	Semivarianzas
857	16	0.43
2677	48	0.61
4033	80	0.90
4734	112	0.87
5317	144	0.72
6139	176	0.64
5699	208	0.68
5336	240	0.72
4964	272	0.65
4365	304	0.69

3.2. Variogramas direccionales

Datos de cobre sin transformar

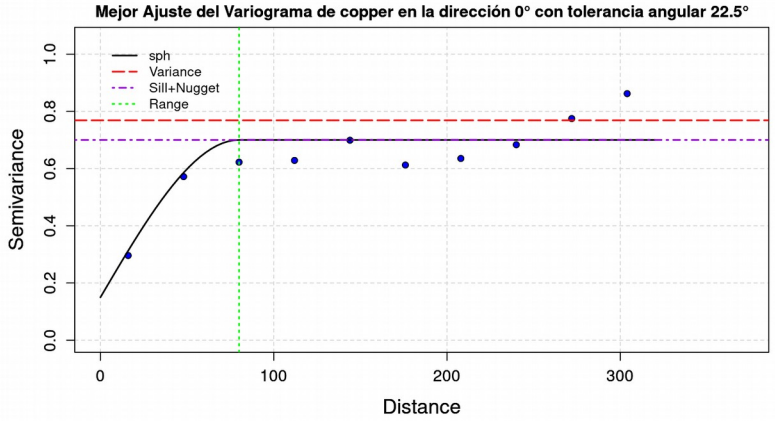




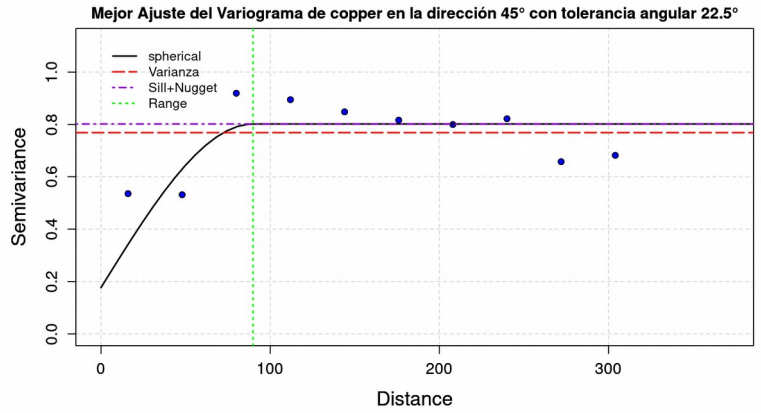
0°±22.5°			45°±22.5°			90°±22.5°			135°±22.5°		
N_ pares	Lags	γ	N_ pares	Lags	γ	N_ pares	Lags	γ	N_ pares	Lags	γ
375	16	0.30	124	16	0.54	224	16	0.45	134	16	0.69
634	48	0.57	737	48	0.53	584	48	0.80	722	48	0.57
1108	80	0.62	989	80	0.92	967	80	1.18	969	80	0.92
1343	112	0.63	1212	112	0.89	1049	112	1.13	1130	112	0.89
1383	144	0.70	1421	144	0.85	1129	144	0.61	1384	144	0.71
2070	176	0.61	1471	176	0.82	1252	176	0.58	1346	176	0.56
1783	208	0.64	1567	208	0.80	1001	208	0.70	1348	208	0.56
2088	240	0.68	1384	240	0.82	762	240	0.74	1102	240	0.63
2084	272	0.77	1199	272	0.66	647	272	0.40	1034	272	0.56
1924	304	0.86	1085	304	0.68	435	304	0.29	921	304	0.52

3.2. Variogramas direccionales

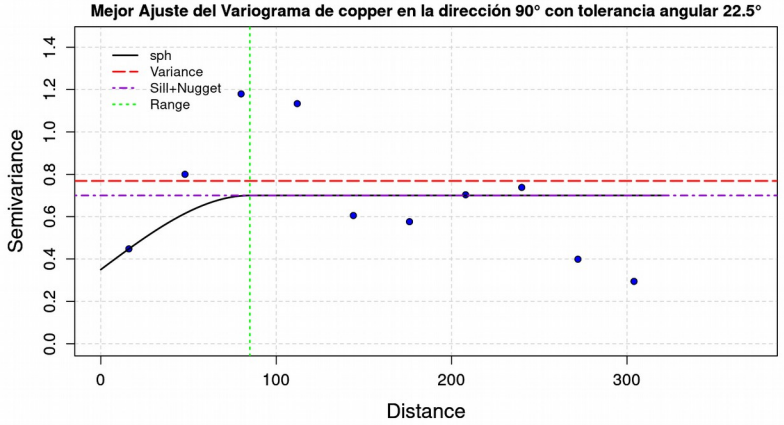
Datos de cobre sin transformar



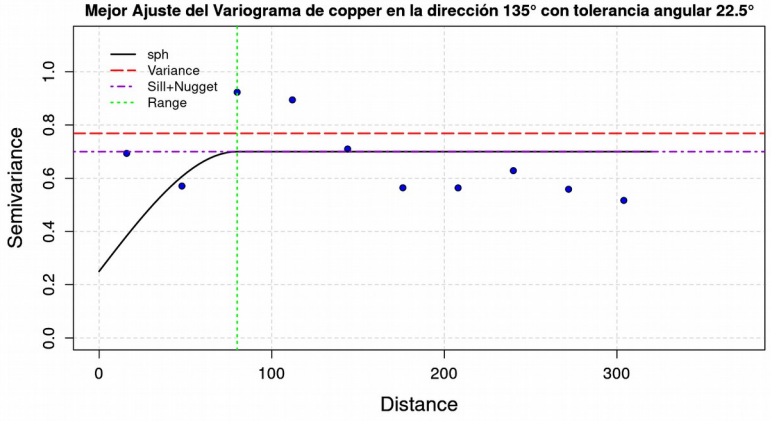
Model	Nugget	Sill+Nugget	Range	MSE
sph	0.1500	0.7000	80.0000	0.0556



Model	Nugget	Sill+Nugget	Range	MSE
spherical	0.1765	0.8017	89.8834	0.1102



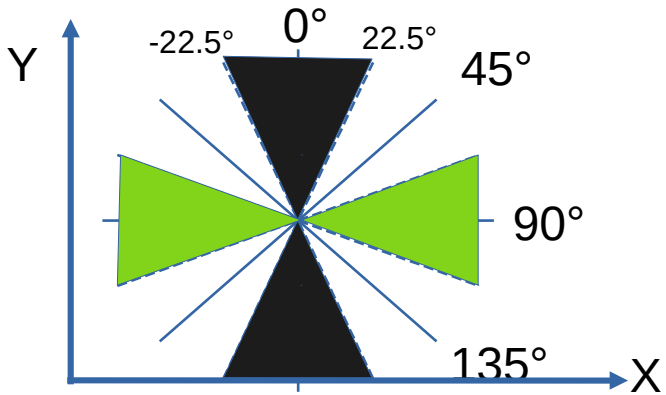
Model	Nugget	Sill+Nugget	Range	MSE
sph	0.3500	0.7000	85.0000	0.7349



Model	Nugget	Sill+Nugget	Range	MSE
sph	0.2500	0.7000	80.0000	0.2809

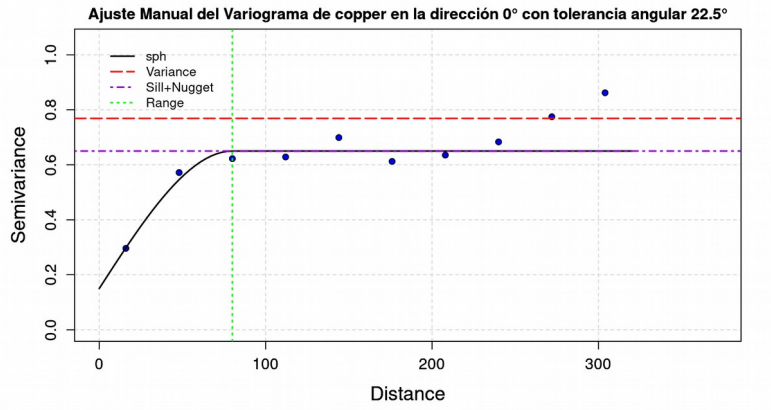
	0° ±22.5°	45° ±22.5°	90° ±22.5°	135° ±22.5°
Model	sph	sph	sph	sph
Nugget	0.15	0.18	0.35	0.25
Sill+ Nugget	0.7	0.80	0.7	0.7
Range	80	90	85	80

$$\lambda = 90/80 = 1.125$$

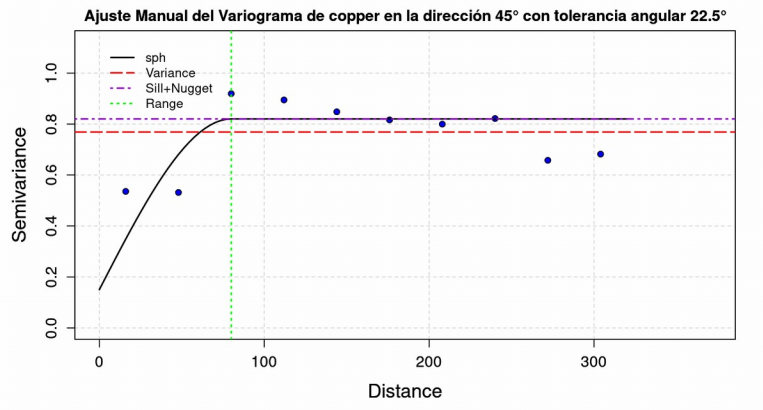


3.2. Variogramas direccionales

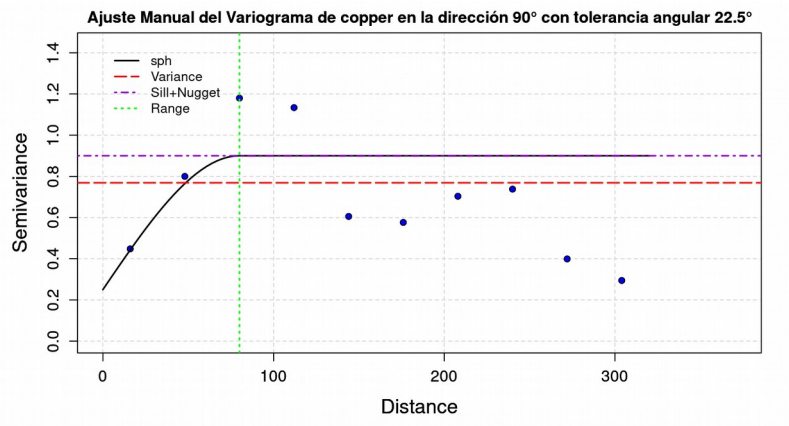
Datos de cobre sin transformar



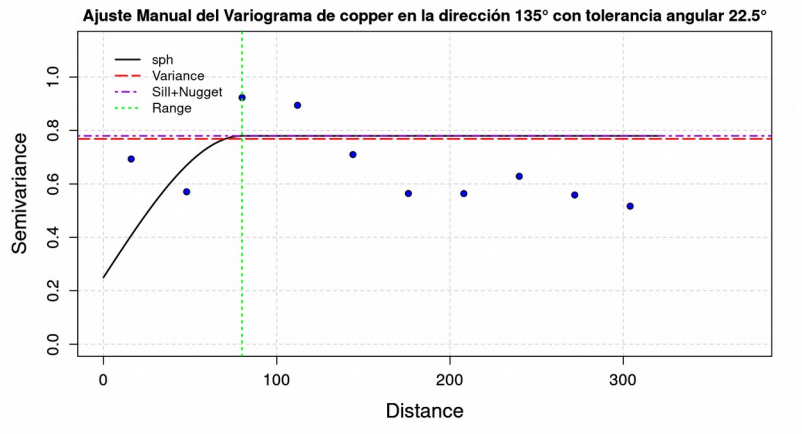
Model	Nugget	Sill+Nugget	Range	MSE
sph	0.1500	0.6500	80.0000	0.0675



Model	Nugget	Sill+Nugget	Range	MSE
sph	0.1500	0.8200	80.0000	0.1193

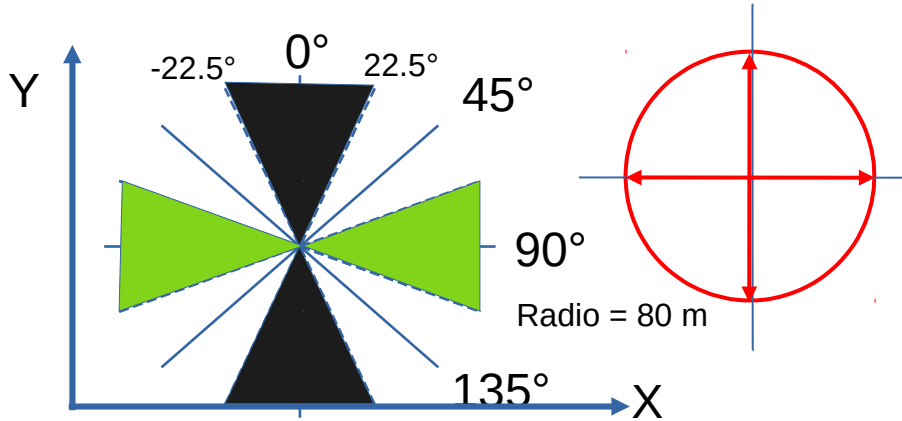


Model	Nugget	Sill+Nugget	Range	MSE
sph	0.2500	0.9000	80.0000	1.0086



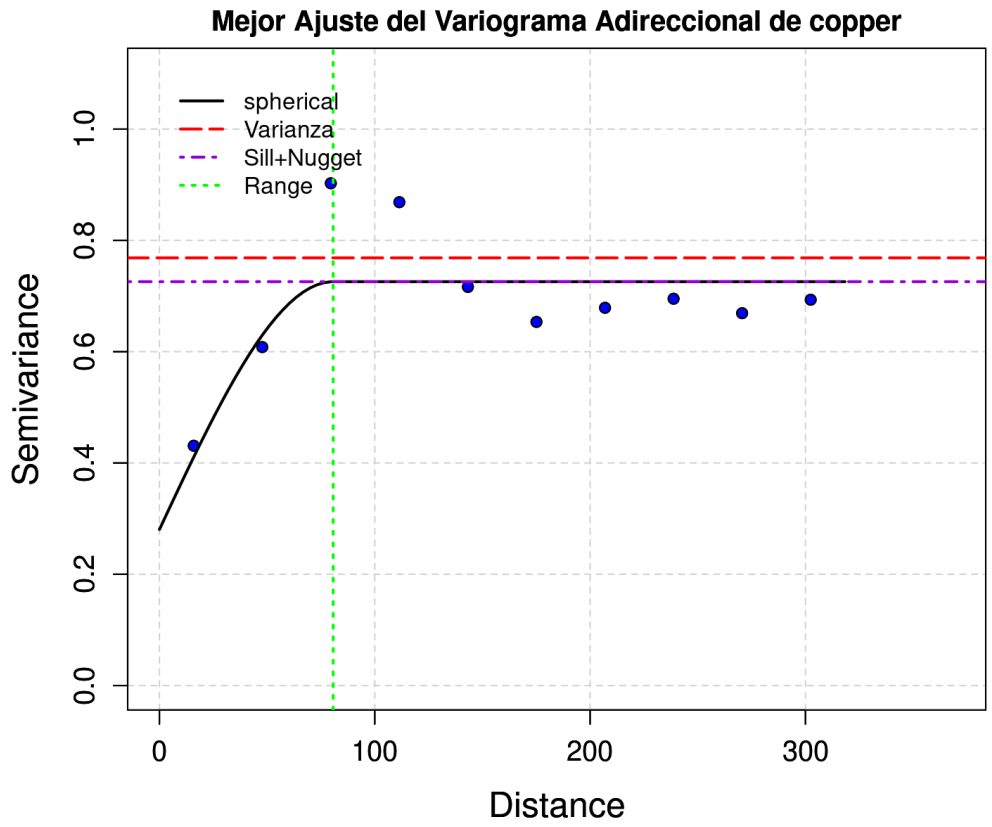
Model	Nugget	Sill+Nugget	Range	MSE
sph	0.2500	0.7800	80.0000	0.3650

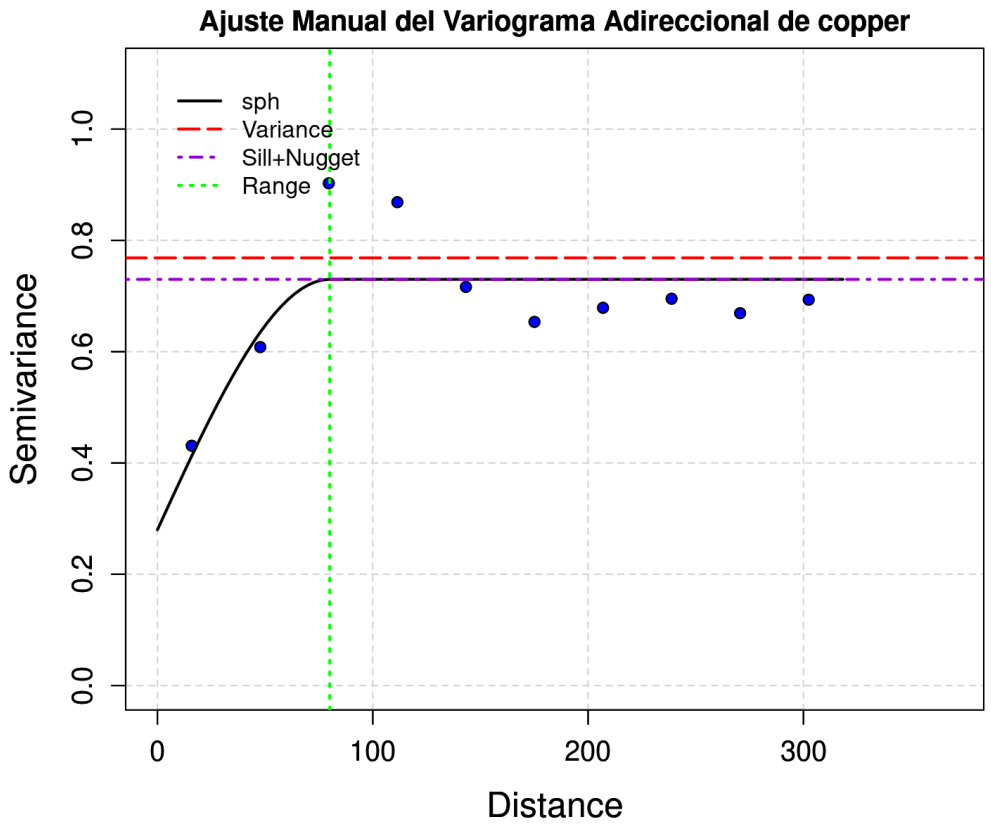
	0° ±22.5°	45° ±22.5°	90° ±22.5°	135° ±22.5°
Model	sph	sph	sph	sph
Nugget	0.15	0.15	0.25	0.25
Sill+ Nugget	0.65	0.82	0.9	0.78
Range	80	80	80	80



3.3. Modelación del variograma

Datos de cobre sin transformar



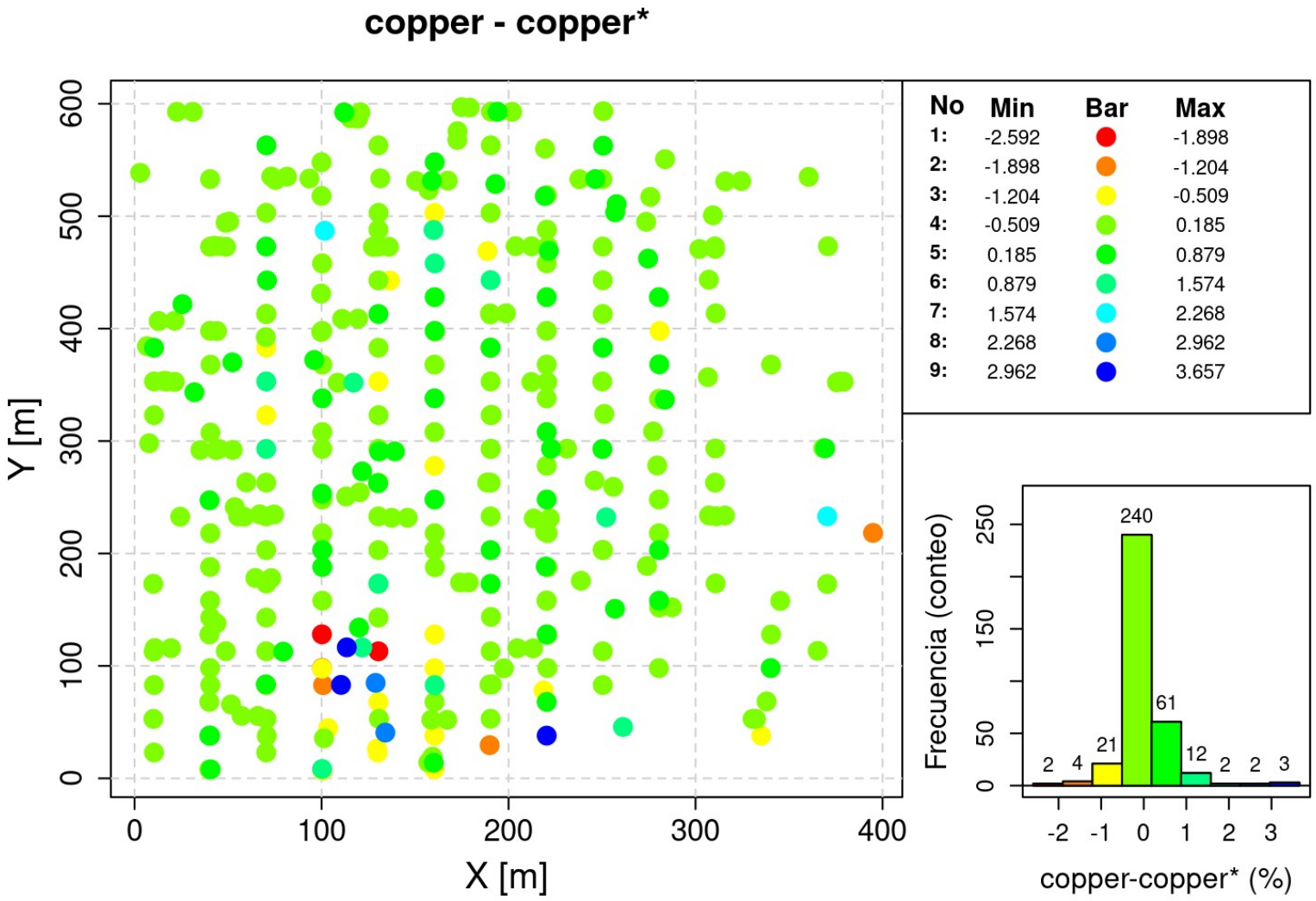


Model	Nugget	Sill+Nugget	Range	MSE
spherical	0.2804	0.7258	80.6772	0.0653

Model	Nugget	Sill+Nugget	Range	MSE
sph	0.2800	0.7300	80.0000	0.0650

3.4. Validación del modelo de variograma

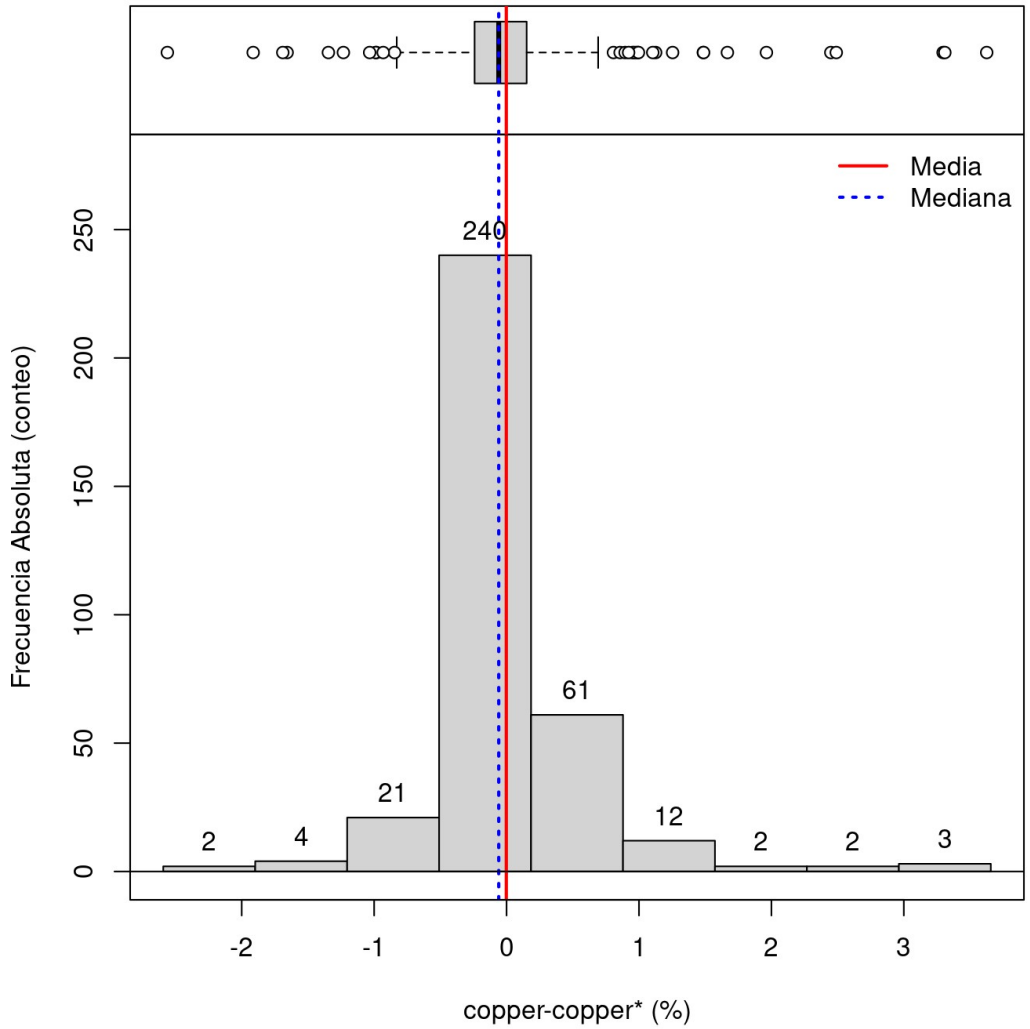
Datos de cobre sin transformar



Estadística	copper-copper*
No_muestras	347
Minimo	-2.56142
Cuartil_1er	-0.24136
Mediana	-0.05905
Media	-0.002
Cuartil_3er	0.15176
Maximo	3.62588
Rango	6.1873
Rango_Intercuartil	0.39313
Varianza	0.34838
Desv_Estandar	0.59024
Simetria	1.90448
Curtosis	14.80984

3.4. Validación del modelo de variograma

Datos de cobre sin transformar

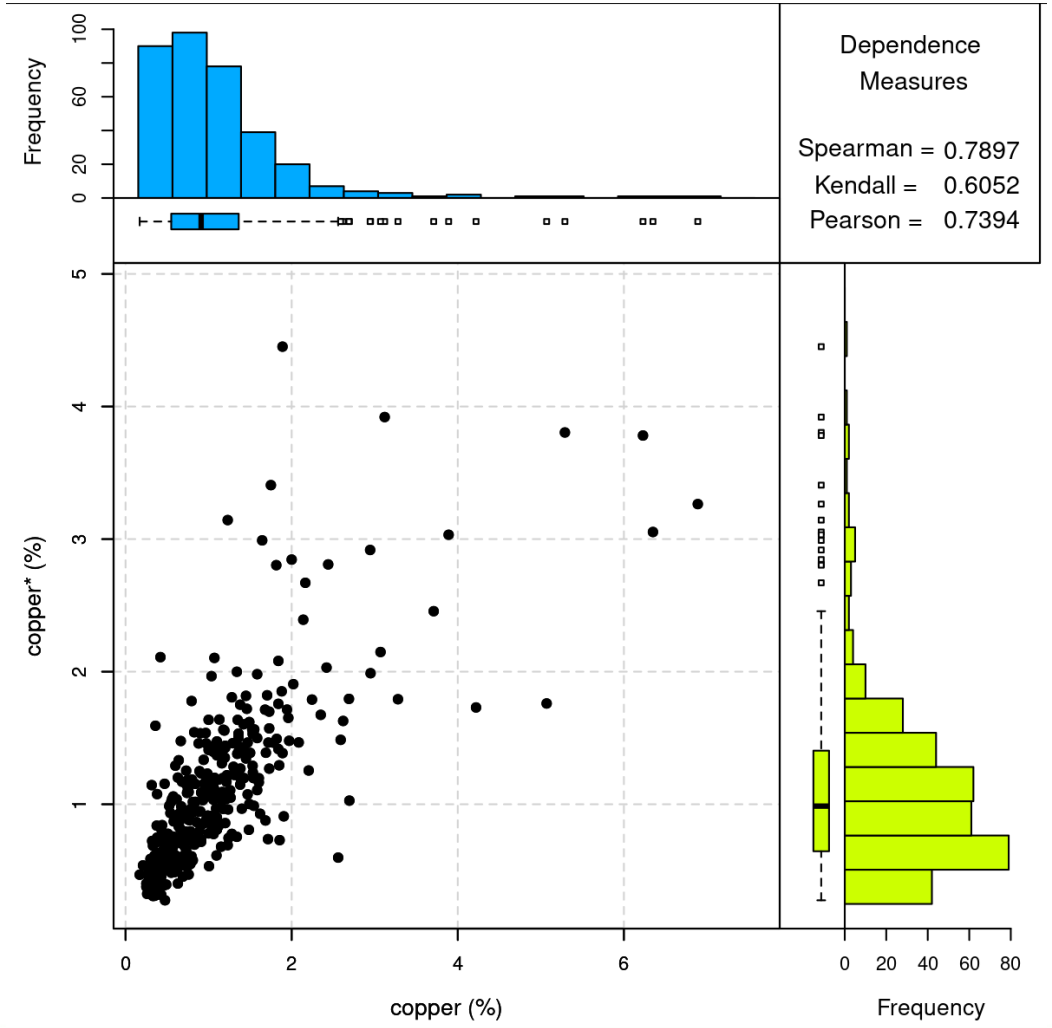


Estadística	copper-copper*
No_muestras	347
Minimo	-2.56142
Cuartil_1er	-0.24136
Mediana	-0.05905
Media	-0.002
Cuartil_3er	0.15176
Maximo	3.62588
Rango	6.1873
Rango_Intercuartil	0.39313
Varianza	0.34838
Desv_Estandar	0.59024
Simetria	1.90448
Curtosis	14.80984

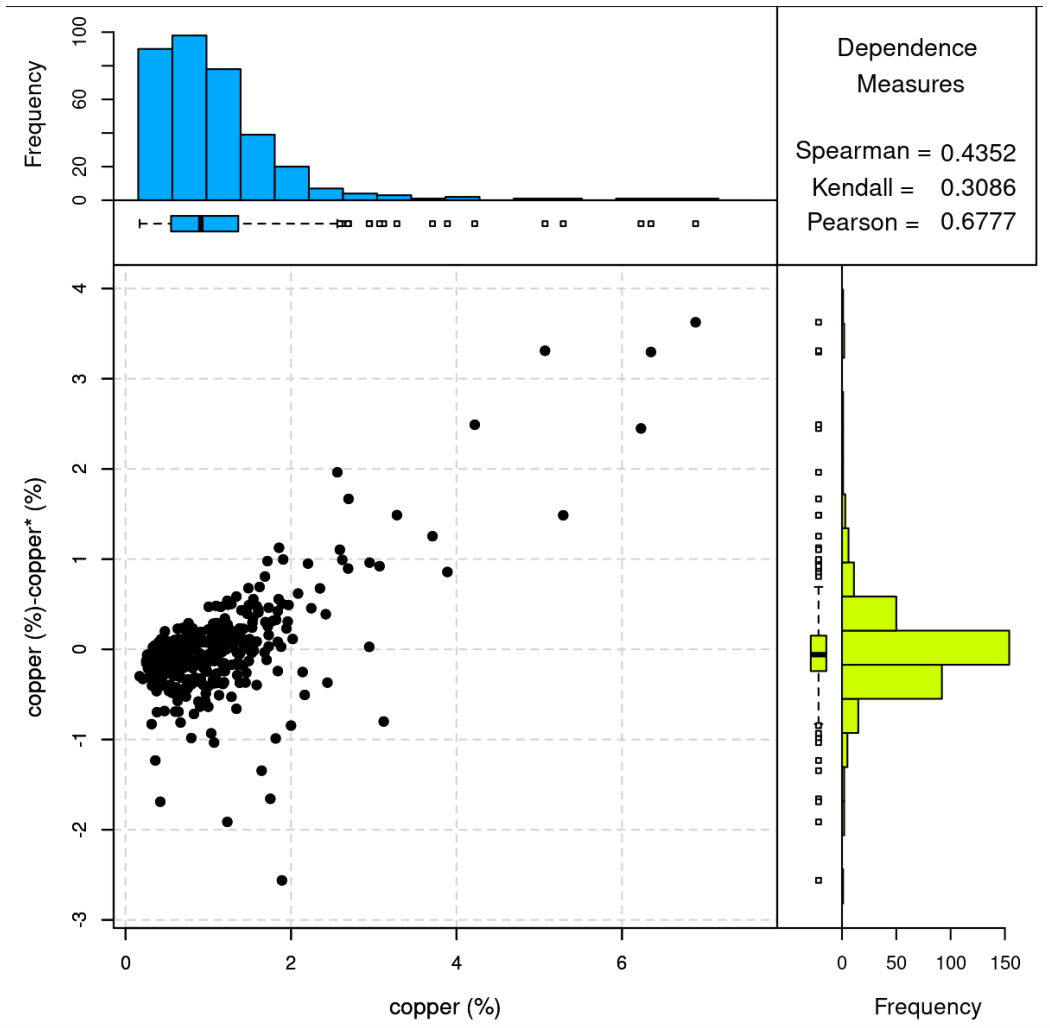
3.4. Validación del modelo de variograma

Datos de cobre sin transformar

copper vs. copper*

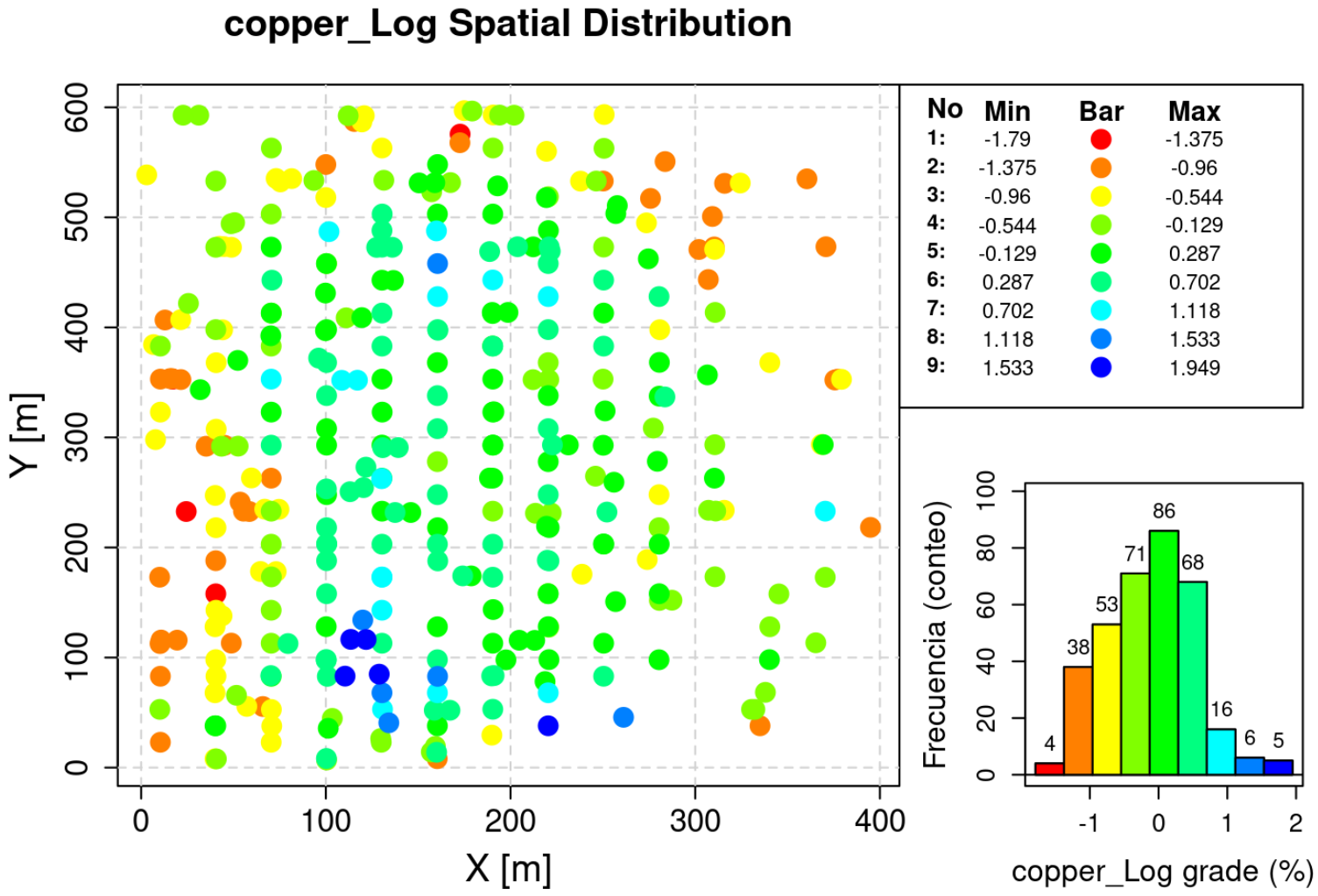


residuos vs. copper



3.1. Análisis de estacionaridad

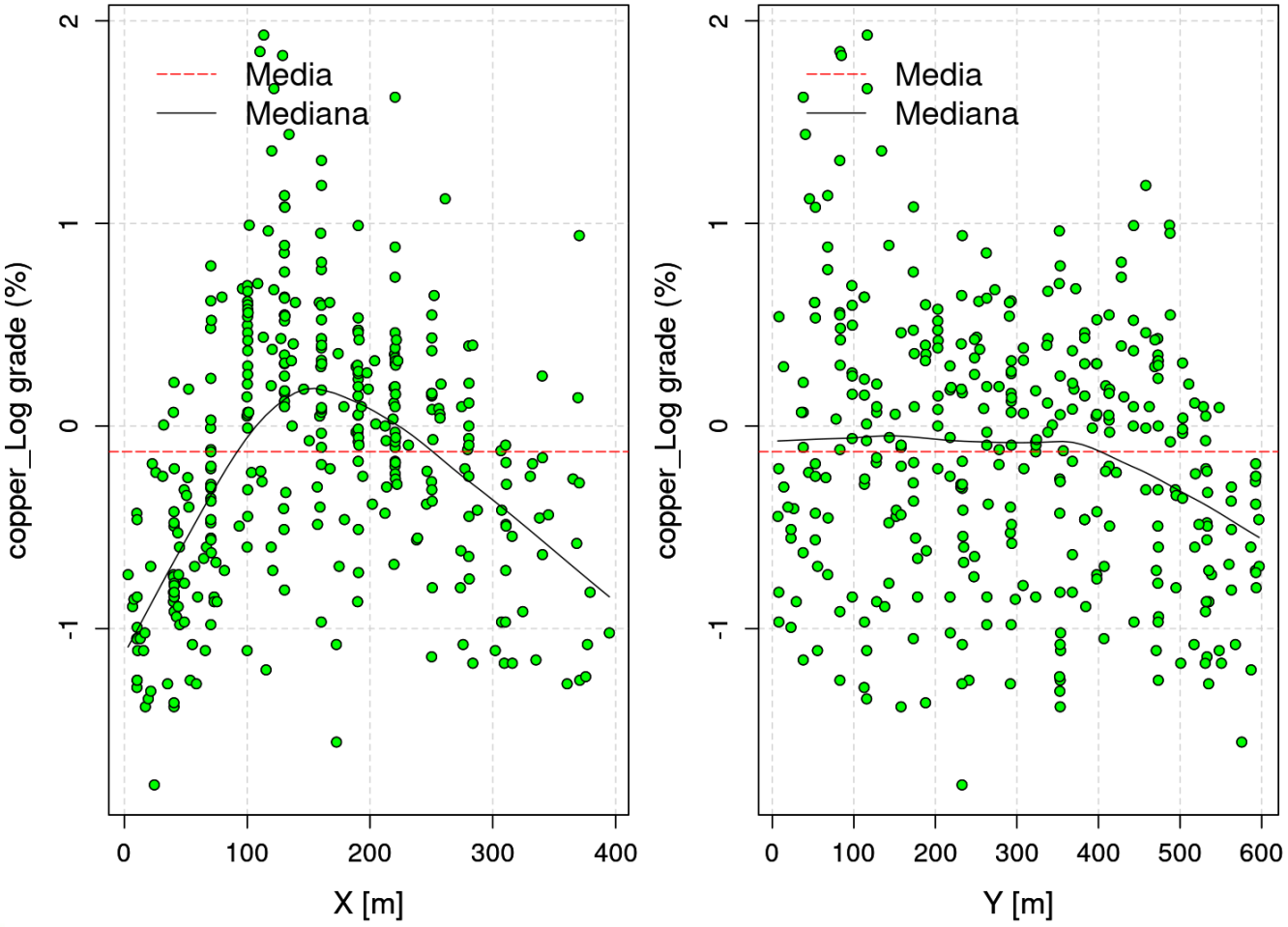
Datos de cobre transformados: Logaritmo



3.1. Análisis de estacionaridad

Datos de cobre transformados: Logaritmo

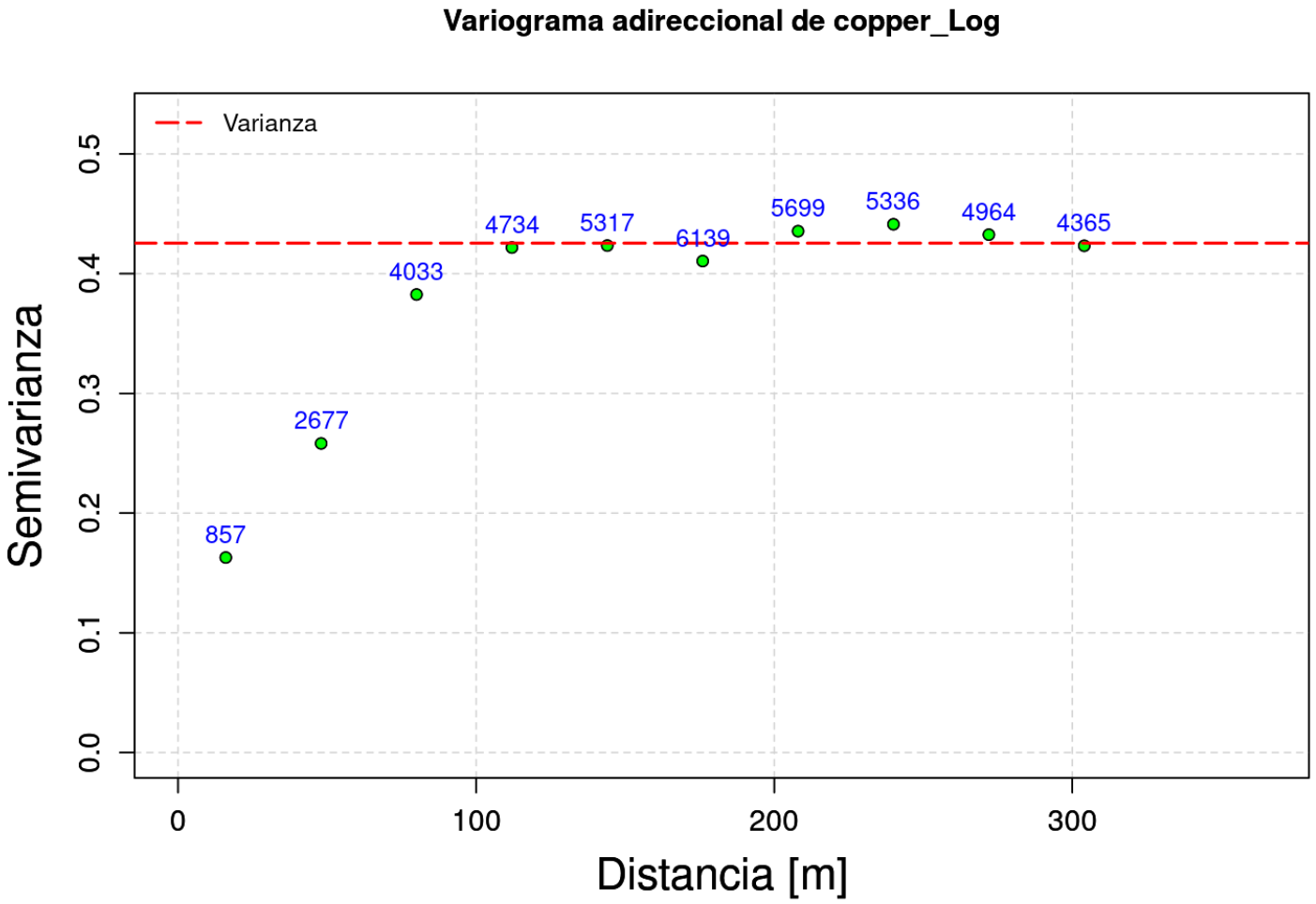
Median Regression Analysis in X and Y directions



3.1. Análisis de estacionaridad

Datos de cobre transformados: Logaritmo

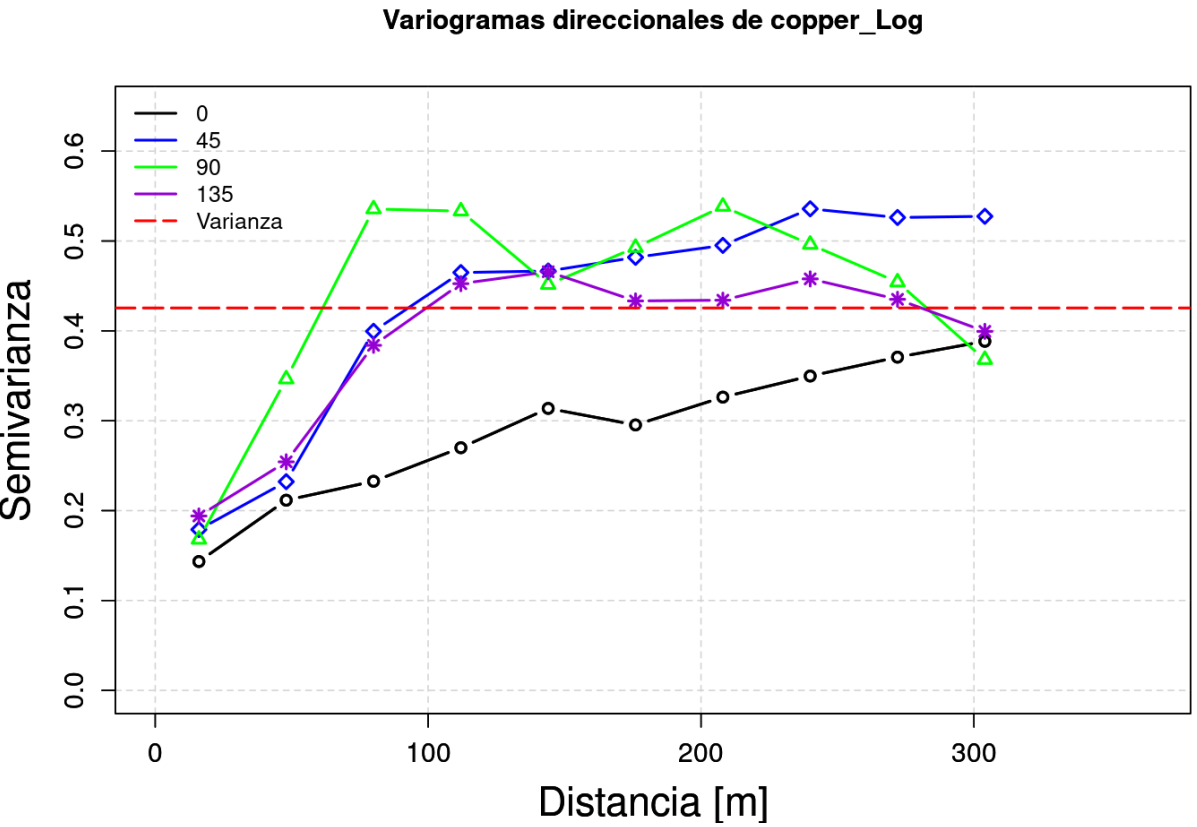
N_lags = 10
DistMin = 0.1 m
DistMax = 636.7078 m
lag_value = max((DistMax/2)/N_lags
= 32 m



Npares	Lags	Semivarianzas
857	16	0.16
2677	48	0.26
4033	80	0.38
4734	112	0.42
5317	144	0.42
6139	176	0.41
5699	208	0.44
5336	240	0.44
4964	272	0.43
4365	304	0.42

3.2. Variogramas direccionales

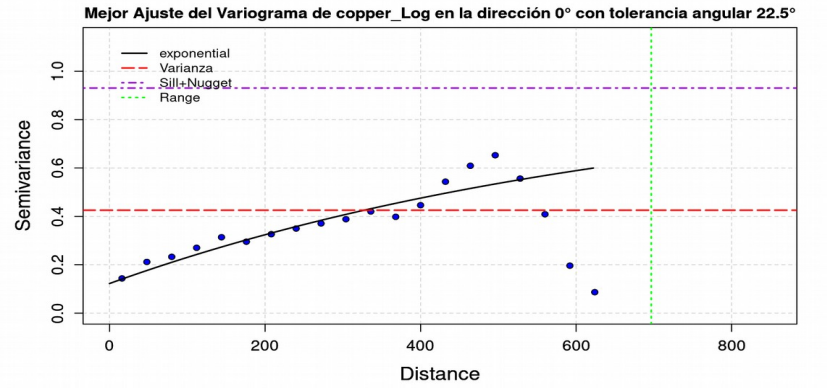
Datos de cobre transformados: Logaritmo



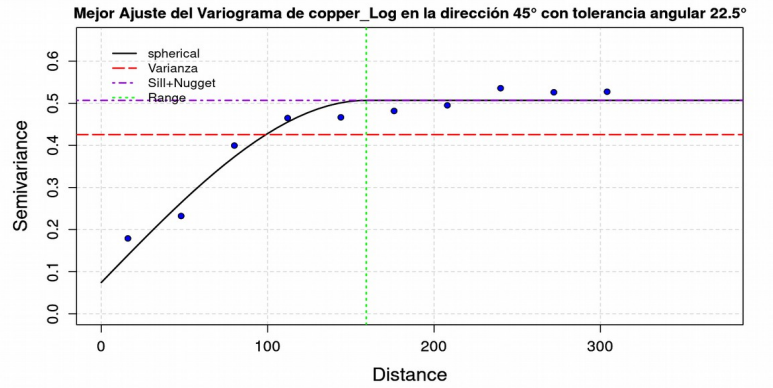
0°±22.5°			45°±22.5°			90°±22.5°			135°±22.5°		
N_ pares	Lags	γ	N_ pares	Lags	γ	N_ pares	Lags	γ	N_ pares	Lags	γ
375	16	0.14	124	16	0.18	224	16	0.17	134	16	0.19
634	48	0.21	737	48	0.23	584	48	0.35	722	48	0.25
1108	80	0.23	989	80	0.40	967	80	0.54	969	80	0.38
1343	112	0.27	1212	112	0.46	1049	112	0.53	1130	112	0.45
1383	144	0.31	1421	144	0.47	1129	144	0.45	1384	144	0.47
2070	176	0.30	1471	176	0.48	1252	176	0.49	1346	176	0.43
1783	208	0.33	1567	208	0.50	1001	208	0.54	1348	208	0.43
2088	240	0.35	1384	240	0.54	762	240	0.50	1102	240	0.46
2084	272	0.37	1199	272	0.53	647	272	0.45	1034	272	0.44
1924	304	0.39	1085	304	0.53	435	304	0.37	921	304	0.40

3.3. Modelación de Variogramas direccionales

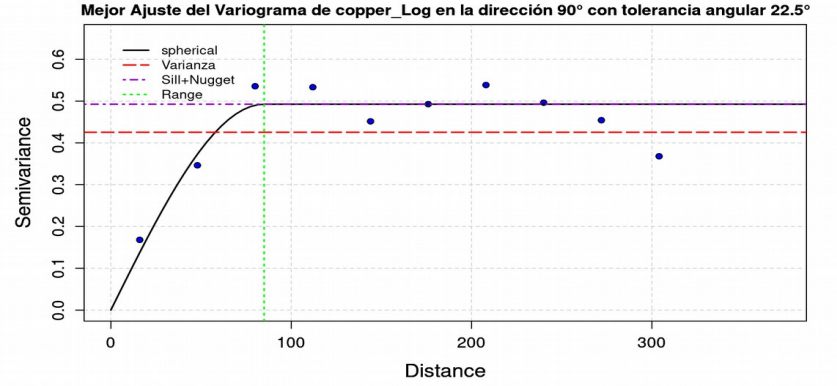
Datos de cobre transformados: Logaritmo



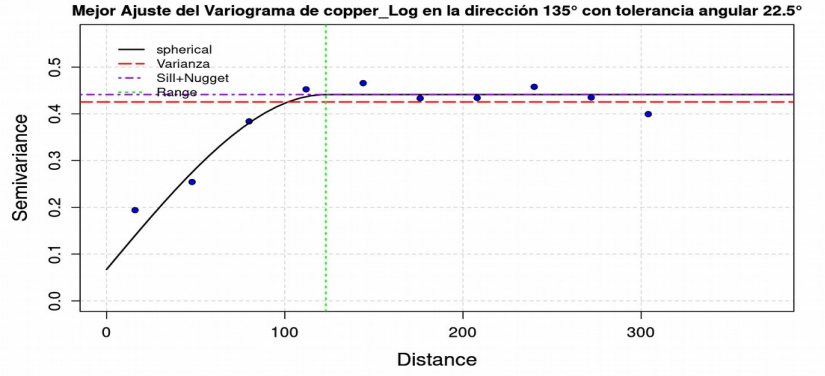
Model	Nugget	Sill+Nugget	Range	MSE
exponential	0.1223	0.9307	696.6341	0.4754



Model	Nugget	Sill+Nugget	Range	MSE
spherical	0.0741	0.5070	159.2848	0.0070



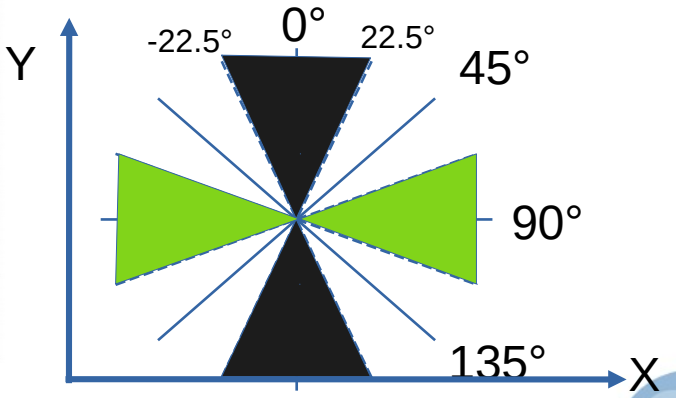
Model	Nugget	Sill+Nugget	Range	MSE
spherical	0.0000	0.4926	84.9933	0.0262



Model	Nugget	Sill+Nugget	Range	MSE
spherical	0.0671	0.4413	123.0814	0.0064

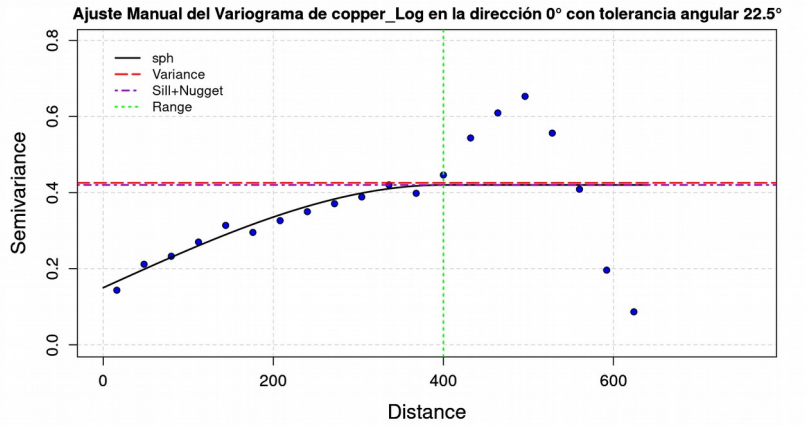
	0° ±22.5°	45° ±22.5°	90° ±22.5°	135° ±22.5°
Model	exp	sph	sph	sph
Nugget	0.12	0.07	0	0.07
Sill+ Nugget	0.93	0.51	0.49	0.44
Range	697	159	85	123

$$\lambda = 697/85 = 8.2 \gg 1$$

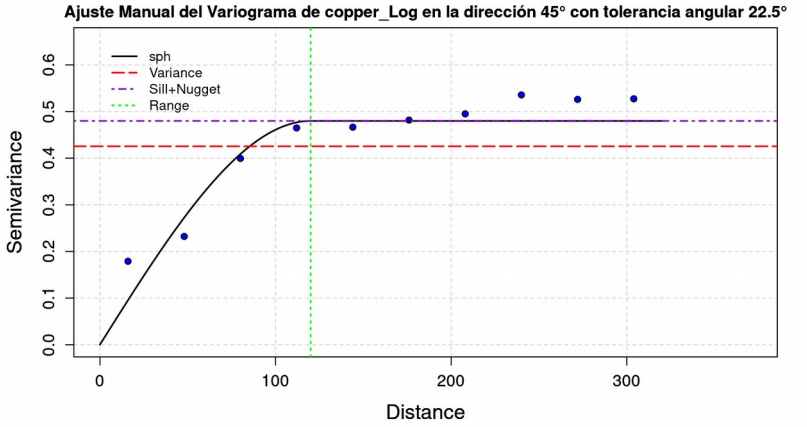


3.3. Modelación de Variogramas direccionales

Datos de cobre transformados: Logaritmo

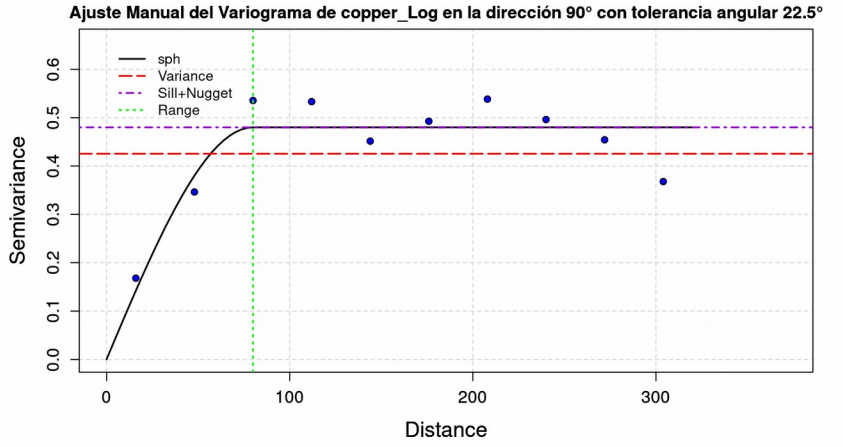


Model	Nugget	Sill+Nugget	Range	MSE
sph	0.1500	0.4200	400.0000	0.2889

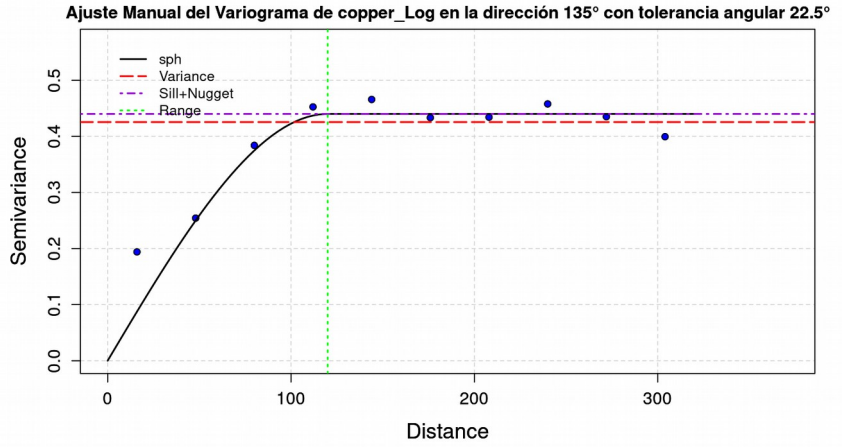


Model	Nugget	Sill+Nugget	Range	MSE
sph	0.0000	0.4800	120.0000	0.0167

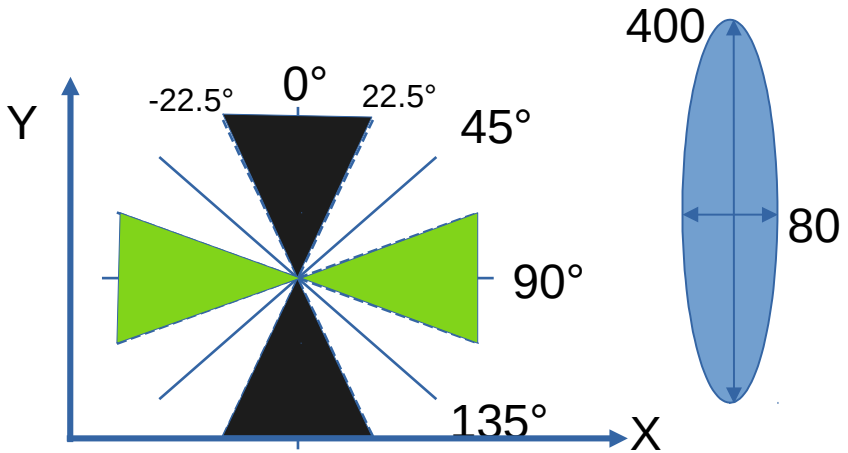
	0° ±22.5°	45° ±22.5°	90° ±22.5°	135° ±22.5°
Model	sph	sph	sph	sph
Nugget	0.15	0	0	0
Sill+ Nugget	0.42	0.48	0.48	0.44
Range	400	120	80	120



Model	Nugget	Sill+Nugget	Range	MSE
sph	0.0000	0.4800	80.0000	0.0256

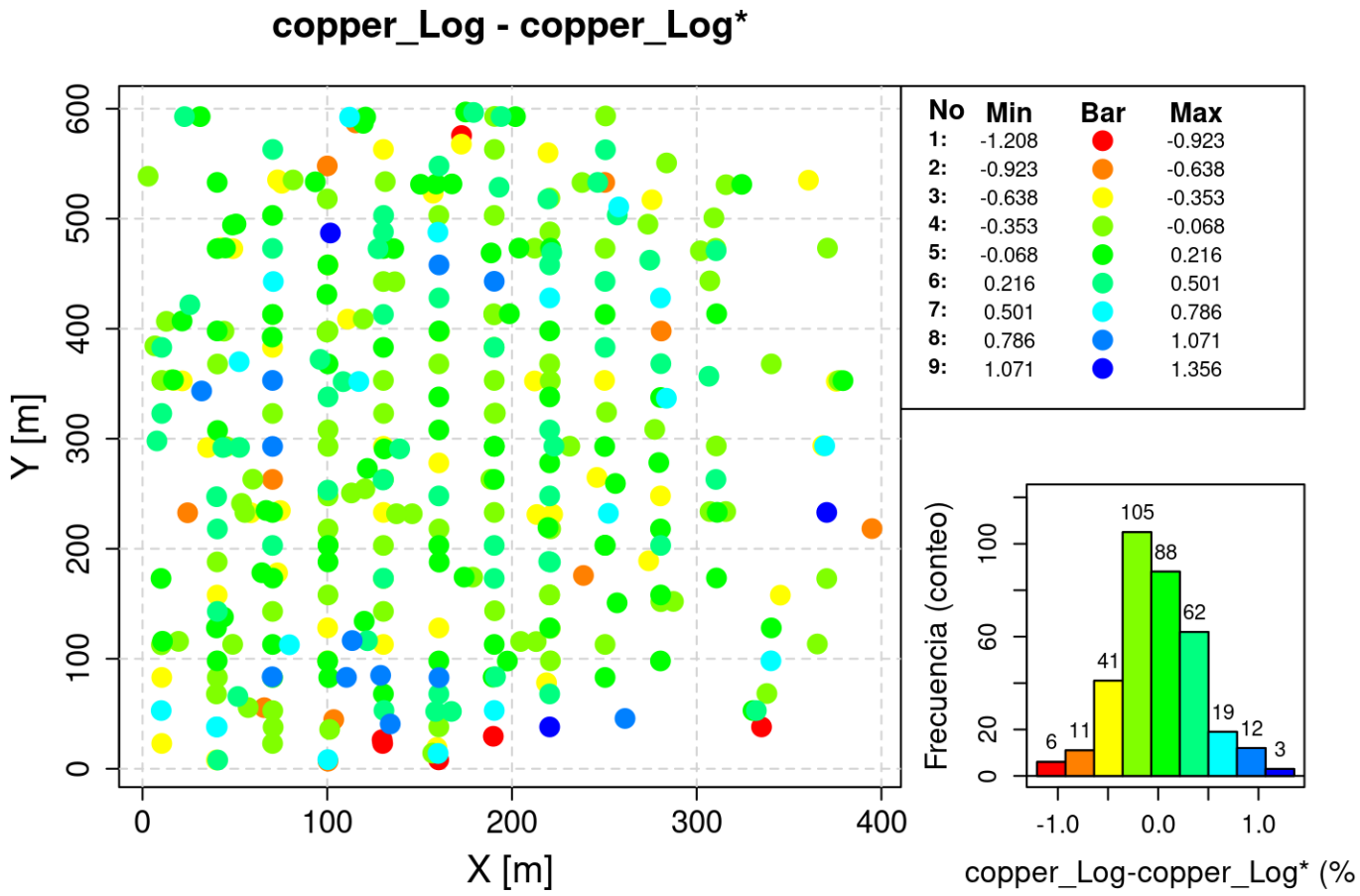


Model	Nugget	Sill+Nugget	Range	MSE
sph	0.0000	0.4400	120.0000	0.0144



3.4. Validación del modelo de variograma

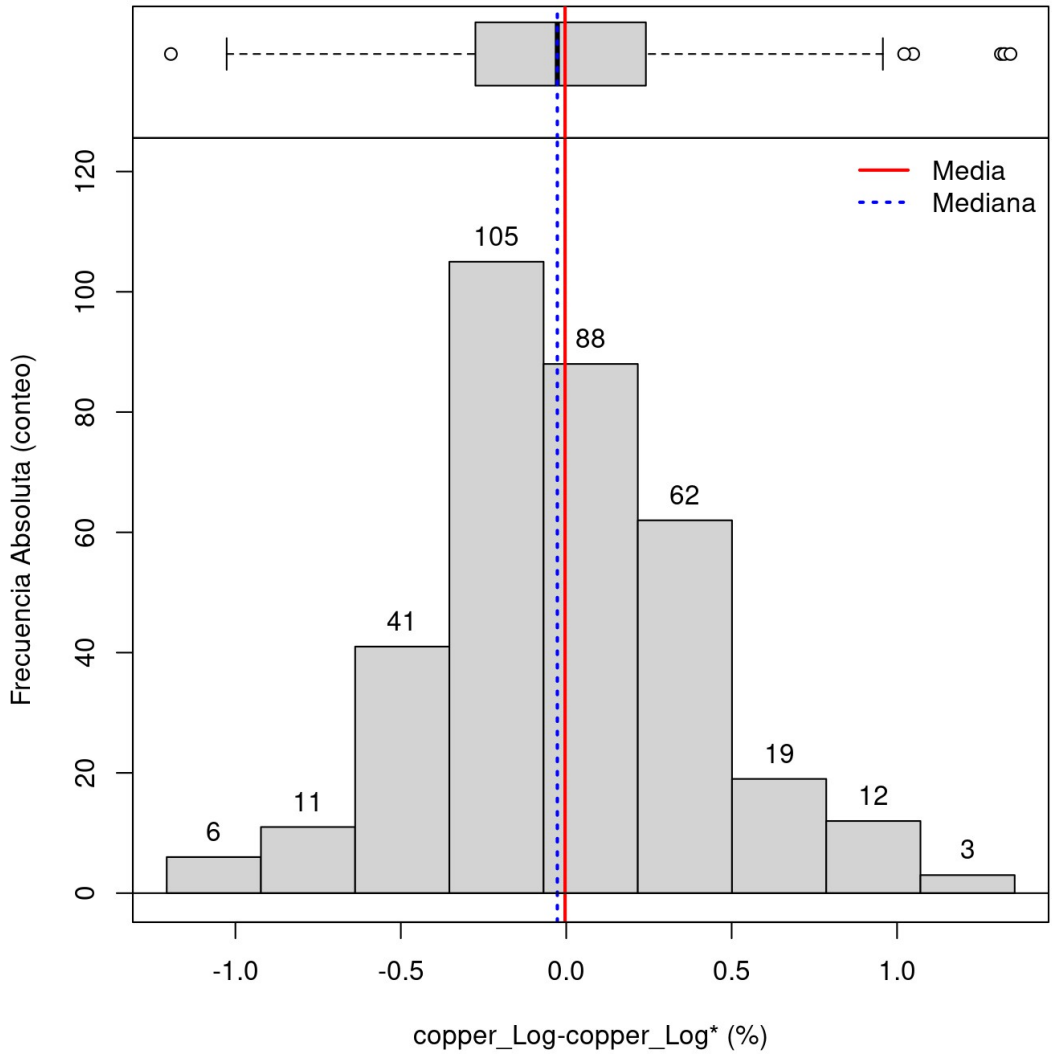
Datos de cobre transformados: Logaritmo



Estadística	Copper_ Log	Copper_ Log*	copper_Log-copper_Log*
No_muestras	347	347	347
Minimo	-1.772	-1.180	-1.195
Cuartil_1er	-0.598	-0.465	-0.275
Mediana	-0.094	-0.033	-0.027
Media	-0.126	-0.123	-0.004
Cuartil_3er	0.309	0.224	0.241
Maximo	1.930	1.186	1.343
Rango	3.702	2.366	2.538
Rango_Intercuartil	0.907	0.689	0.515
Varianza	0.425	0.243	0.163
Desv_Estandar	0.652	0.493	0.404
Simetria	0.194	-0.077	0.326
Curtosis	3.017	2.528	3.751

3.4. Validación del modelo de variograma

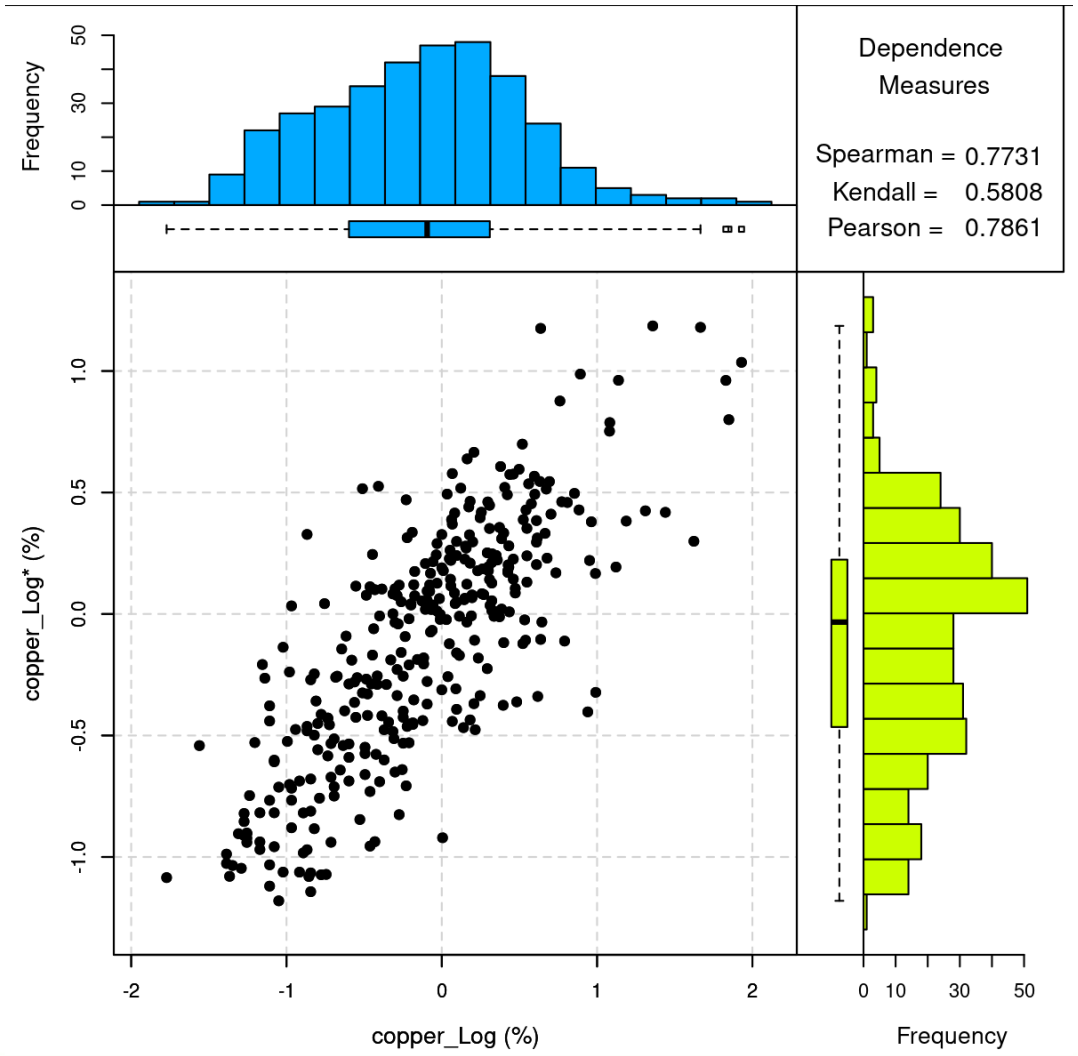
Datos de cobre transformados: Logaritmo

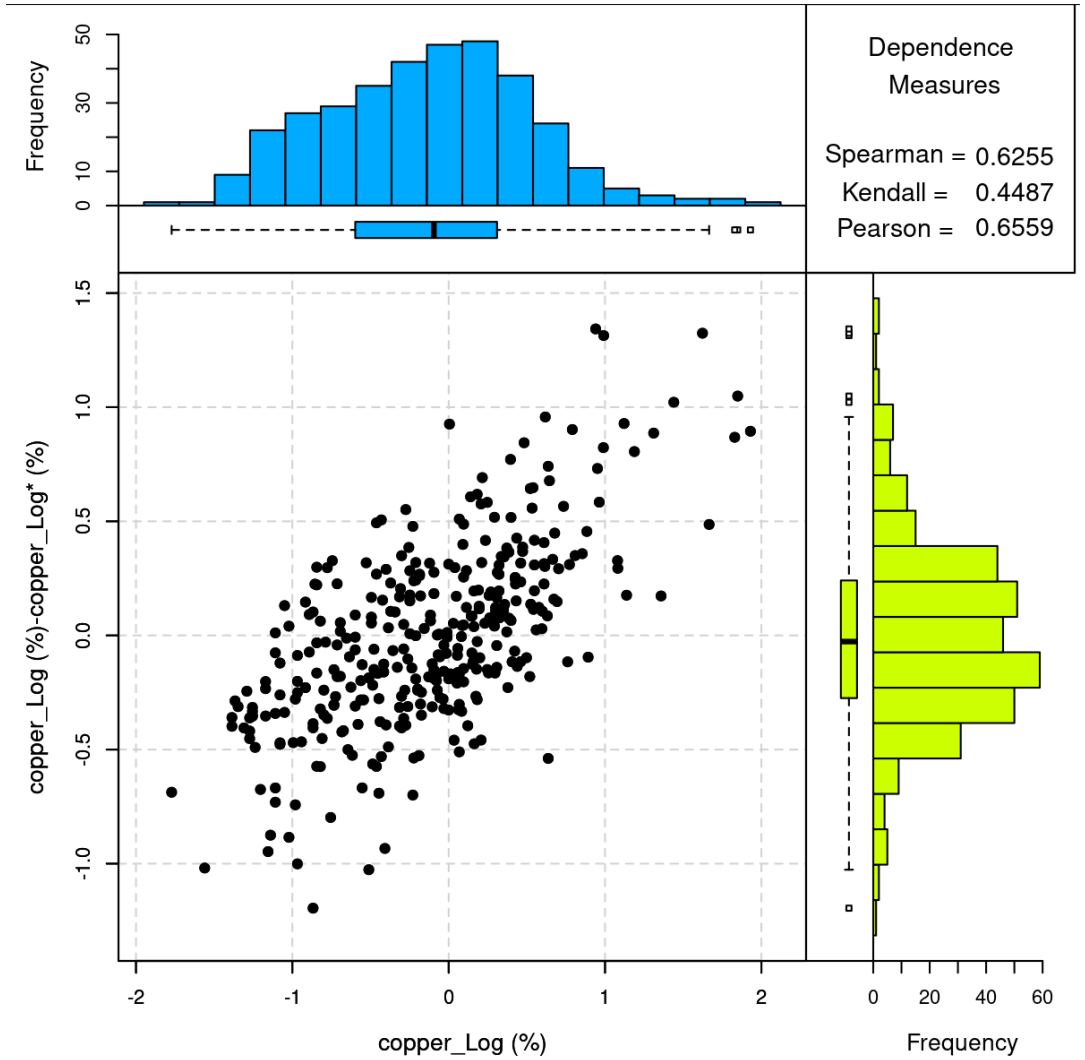


Estadística	copper_Log-copper_Log*
No_muestras	347
Minimo	-1.195
Cuartil_1er	-0.275
Mediana	-0.027
Media	-0.004
Cuartil_3er	0.241
Maximo	1.343
Rango	2.538
Rango_Intercuartil	0.515
Varianza	0.163
Desv_Estandar	0.404
Simetria	0.326
Curtosis	3.751

3.4. Validación del modelo de variograma

Datos de cobre transformados: Logaritmo



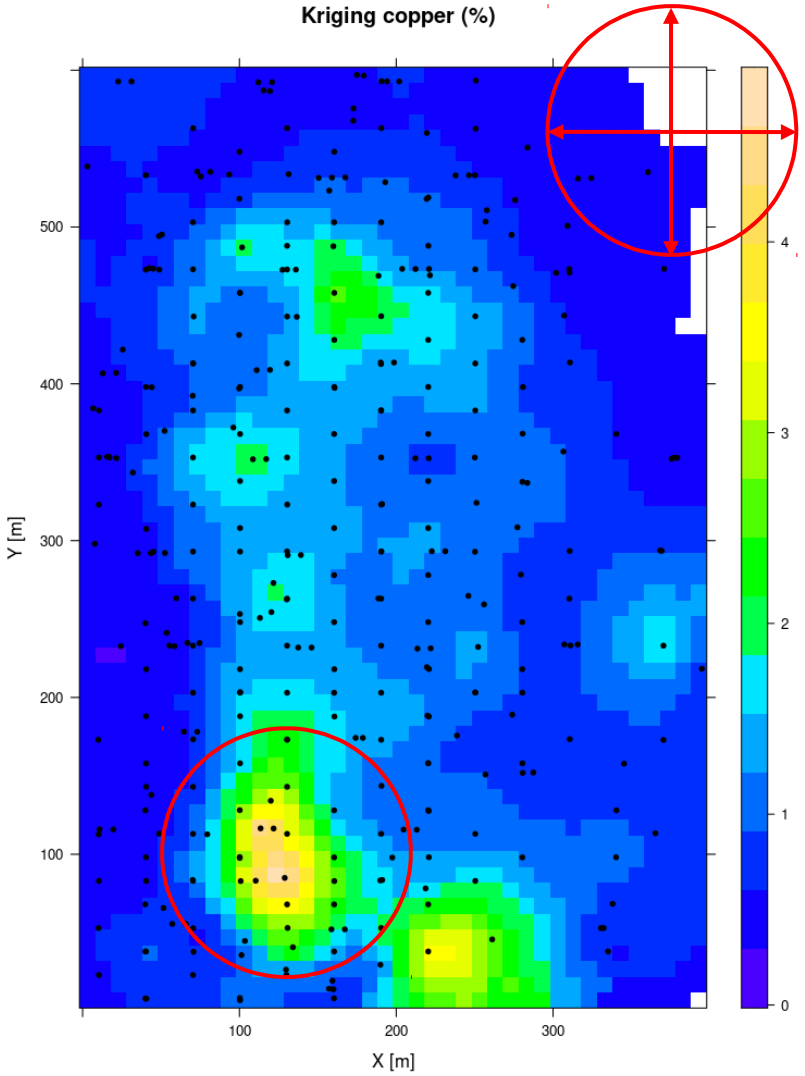


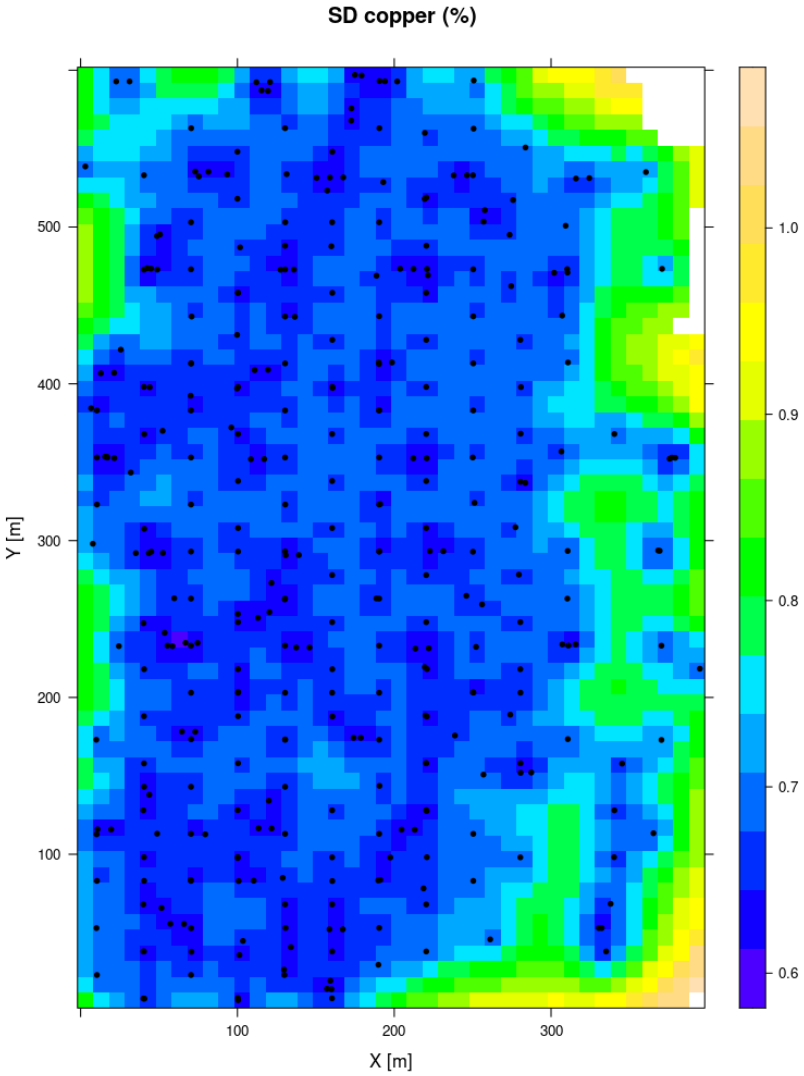
4. Estimación espacial

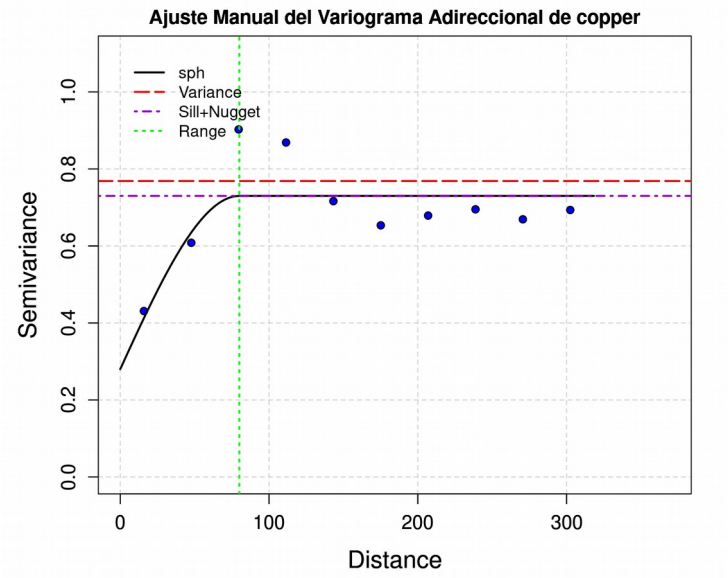
4.1. Estimación espacial univariada

4.1. Estimación espacial univariada

Kriging Ordinario Puntual de cobre sin transformar (isotrópico)







Model	Nugget	Sill+Nugget	Range	MSE
sph	0.2800	0.7300	80.0000	0.0650

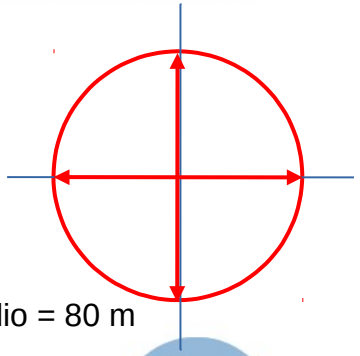
DistMin = 0.1 m

DistMax = 636.7078 m

Malla: 10 m x 10 m

MinPoints = 4

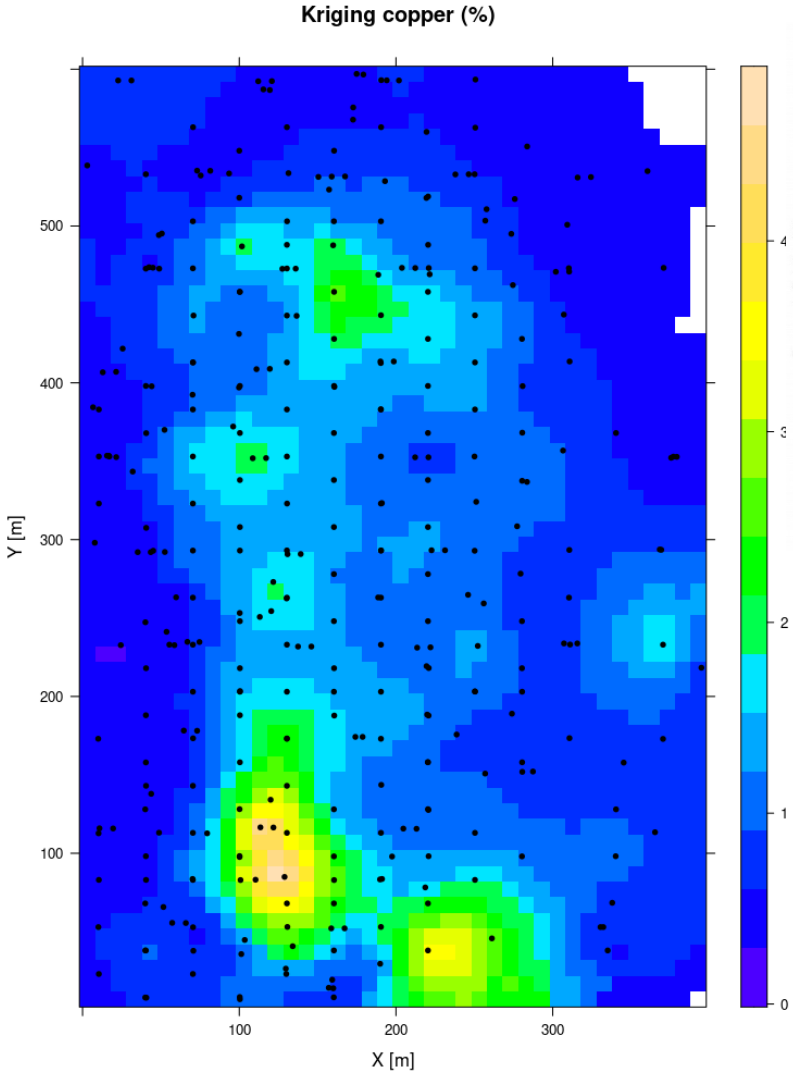
MaxPoints = 10

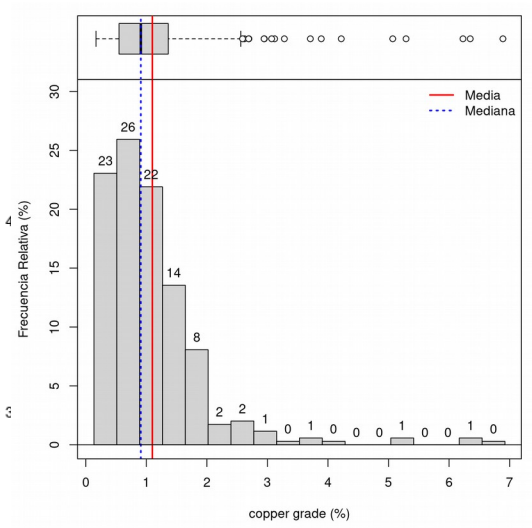


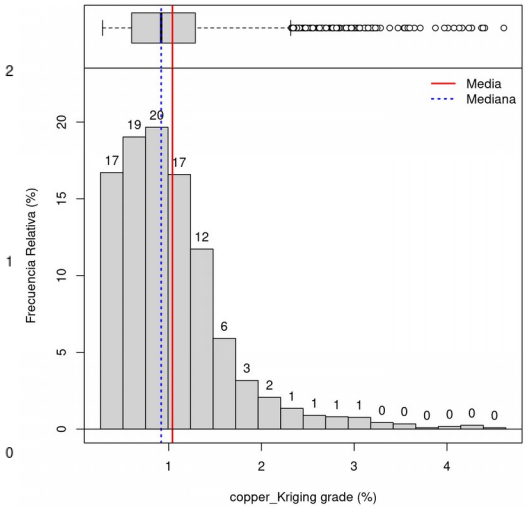
Radio = 80 m

4.1. Estimación espacial univariada

Kriging Ordinario Puntual de cobre sin transformar (isotrópico)



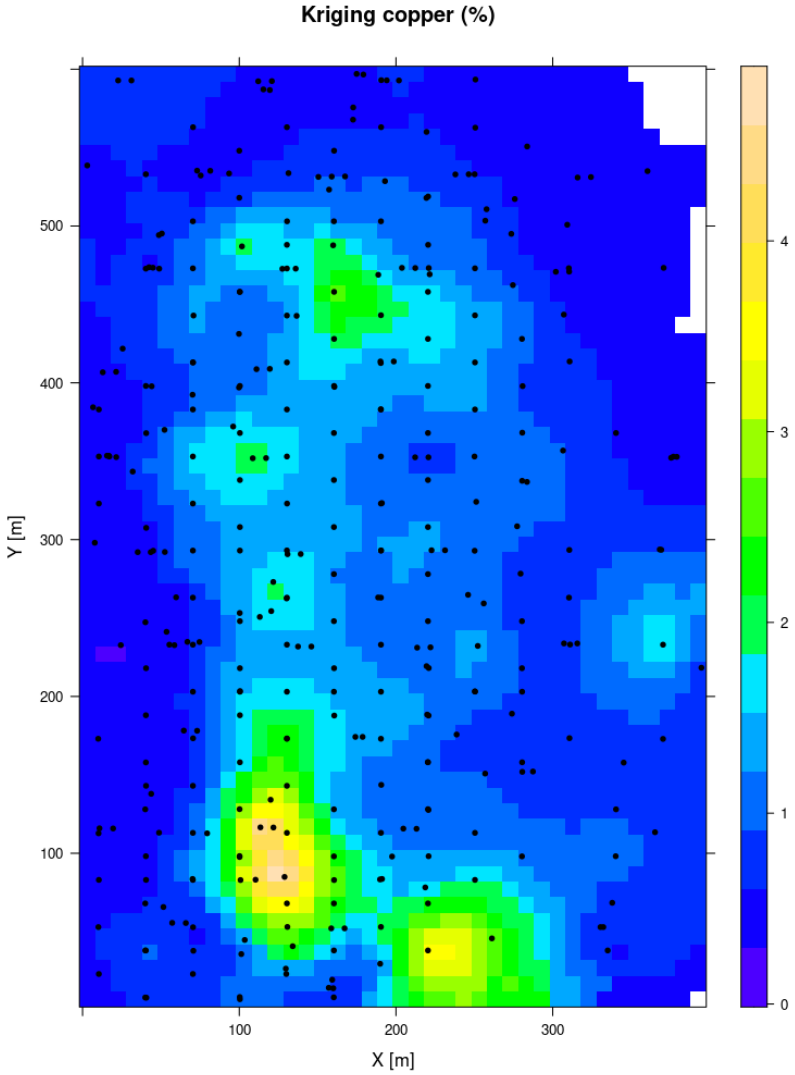




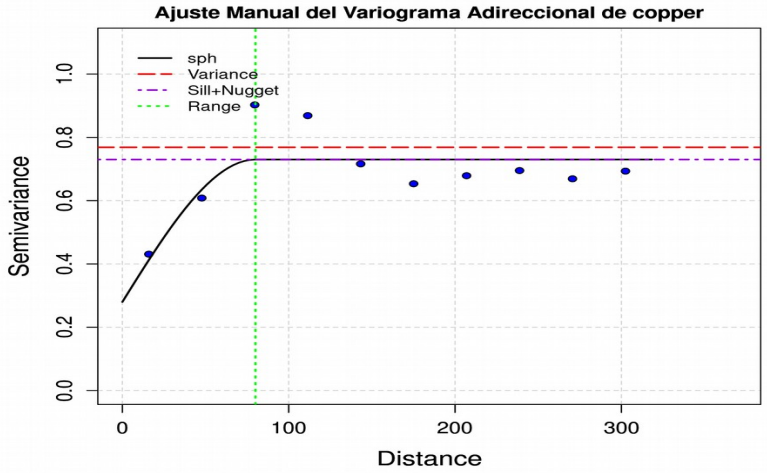
Estadística	Data copper	Kriging copper
No_muestras	347	2370
Minimo	0.17	0.29
Cuartil_1er	0.55	0.60
Mediana	0.91	0.92
Media	1.10	1.04
Cuartil_3er	1.36	1.29
Maximo	6.89	4.61
Rango	6.72	4.33
Rango_Intercuartil	0.81	0.69
Varianza	0.77	0.39
Desv_Estandar	0.88	0.62
Simetria	3.11	1.84
Curtosis	17.12	8.07

4.1. Estimación espacial univariada

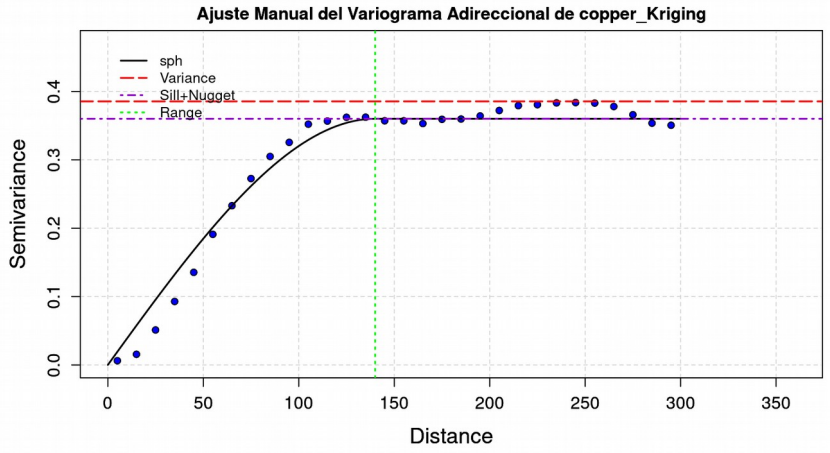
Kriging Ordinario Puntual de cobre sin transformar (isotrópico)



	Data copper	Kriging copper
Model	sph	sph
Nugget	0.28	0
Sill+ Nugget	0.73	0.36
Range	80	140



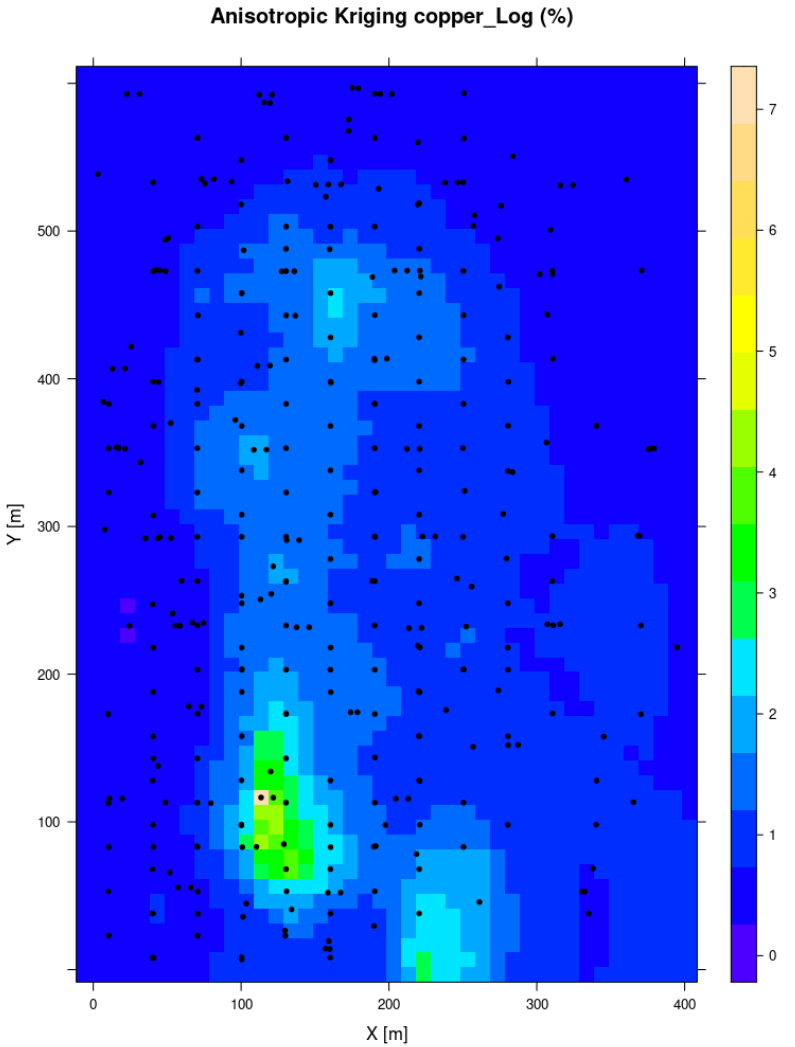
Model	Nugget	Sill+Nugget	Range	MSE
sph	0.2800	0.7300	80.0000	0.0650

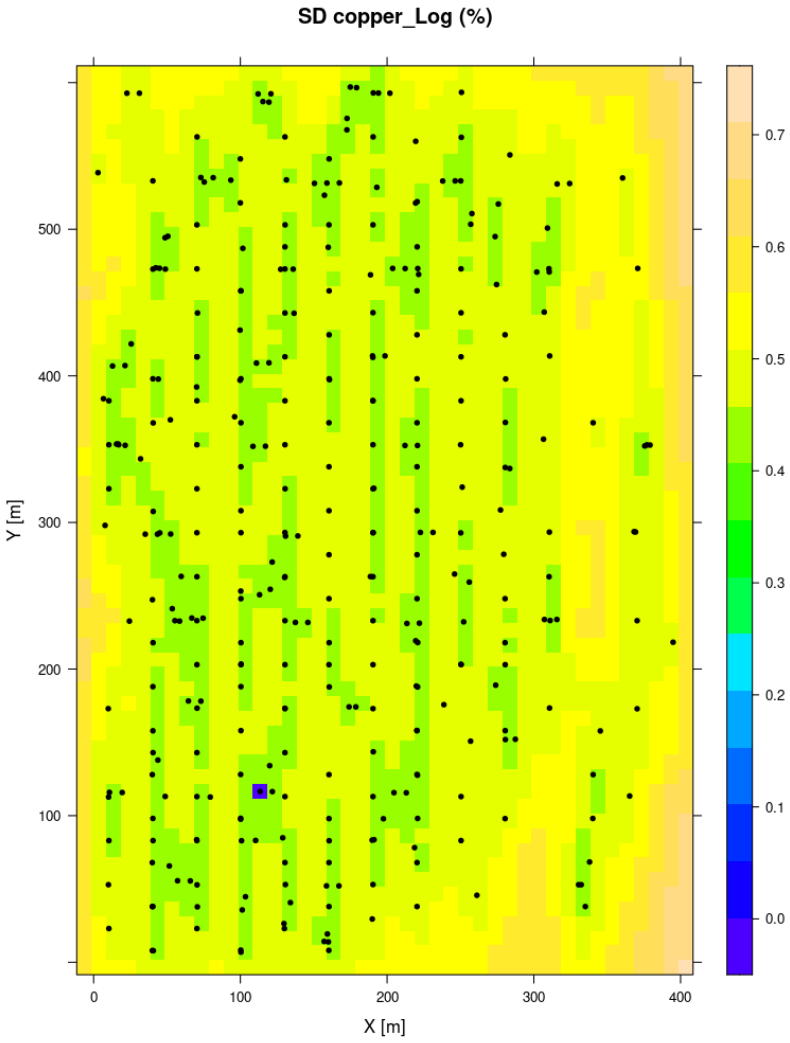


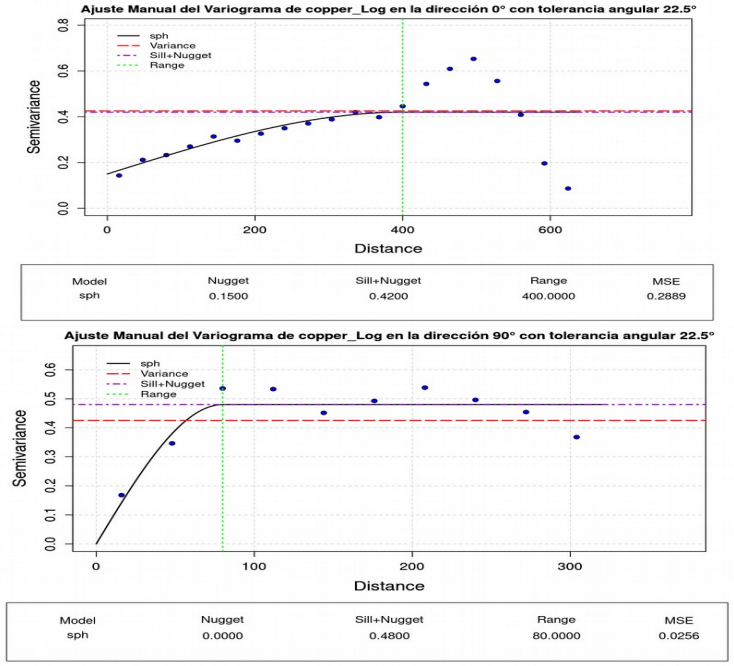
Model	Nugget	Sill+Nugget	Range	MSE
sph	0.0000	0.3600	140.0000	0.0111

4.1. Estimación espacial univariada

Kriging Ordinario Puntual de cobre transformado (anisotrópico)







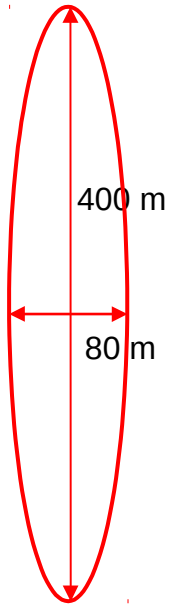
DistMin = 0.1 m

DistMax = 636.7078 m

Malla: 10 m x 10 m

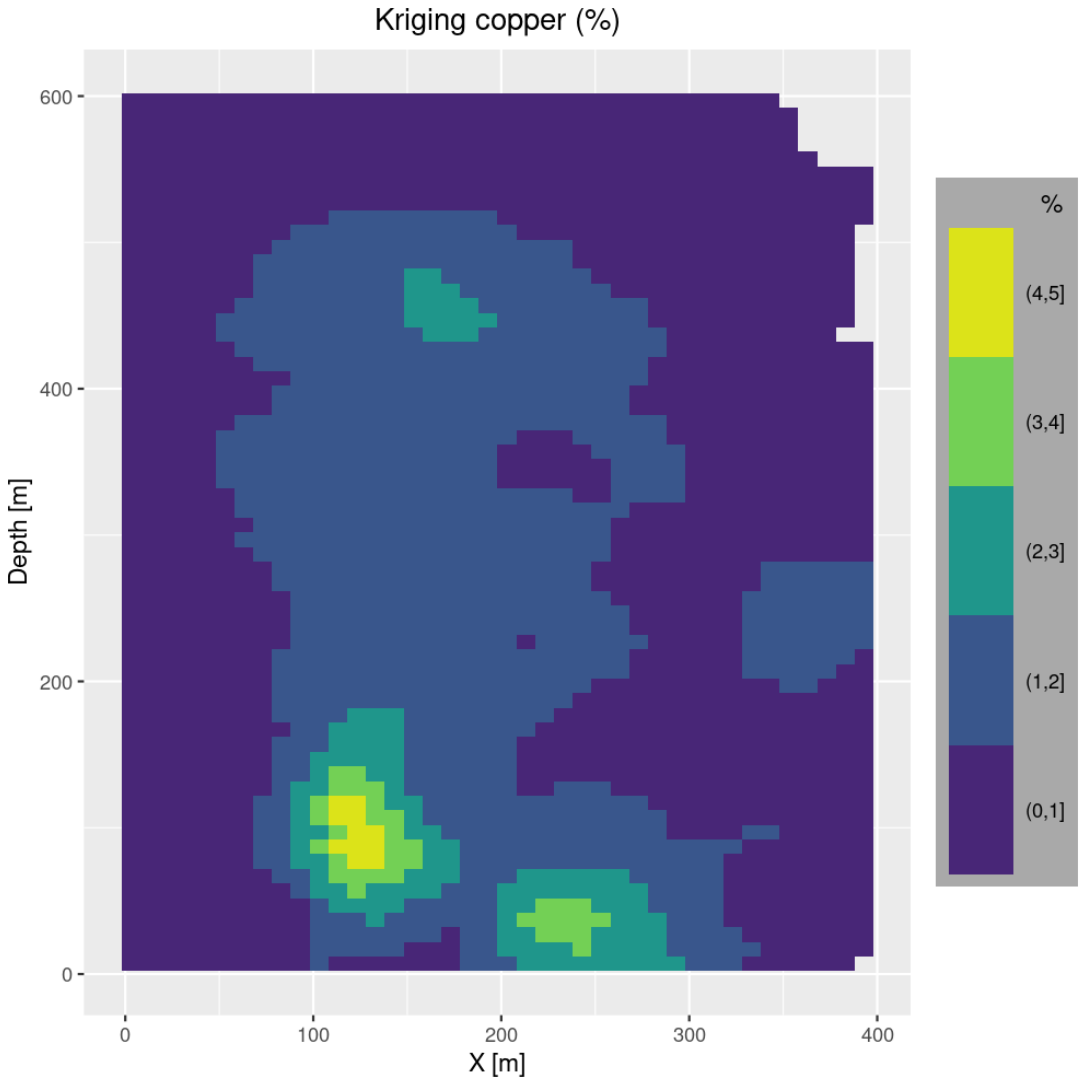
MinPoints = 4

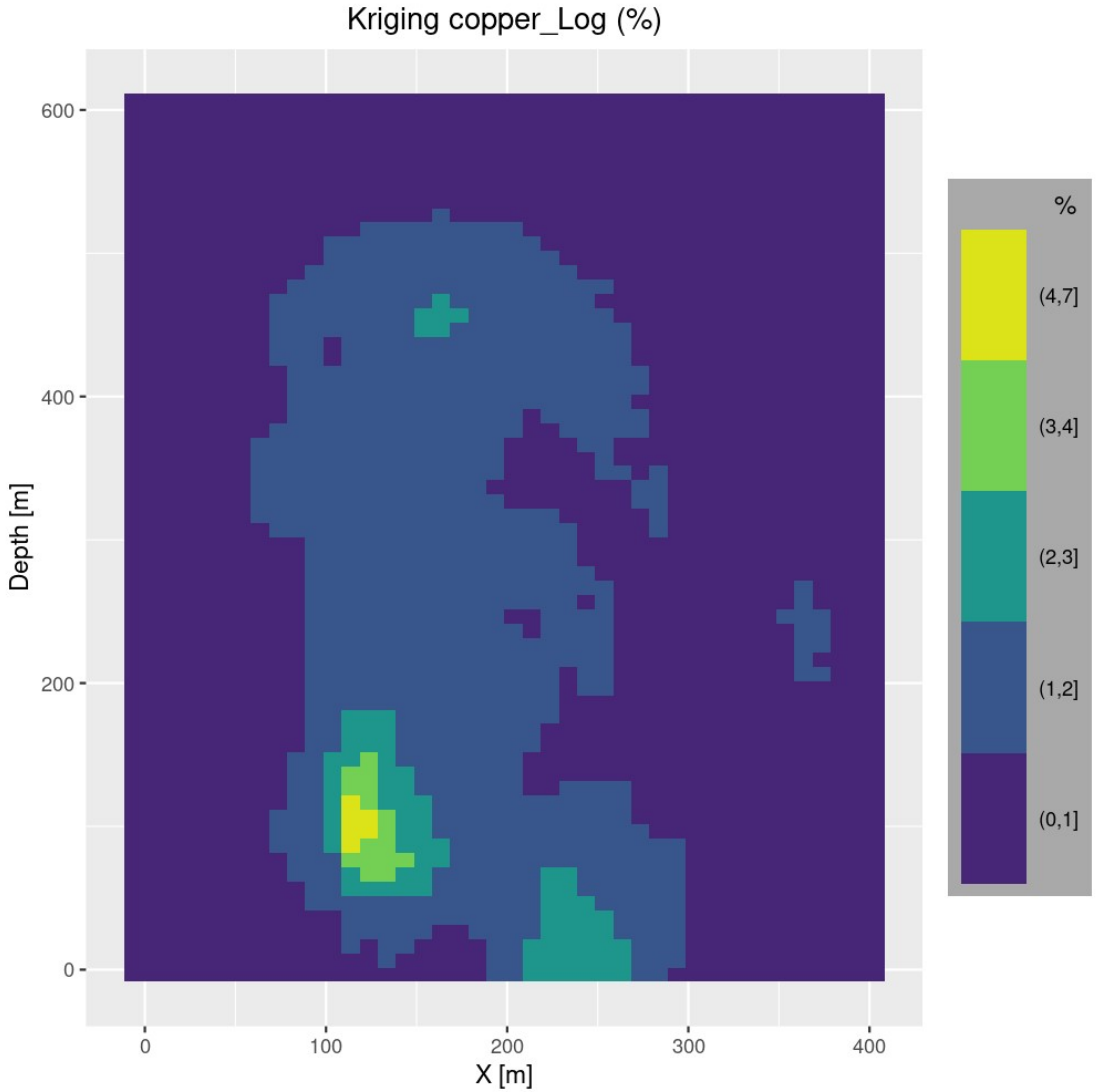
MaxPoints = 10



4.1. Estimación espacial univariada

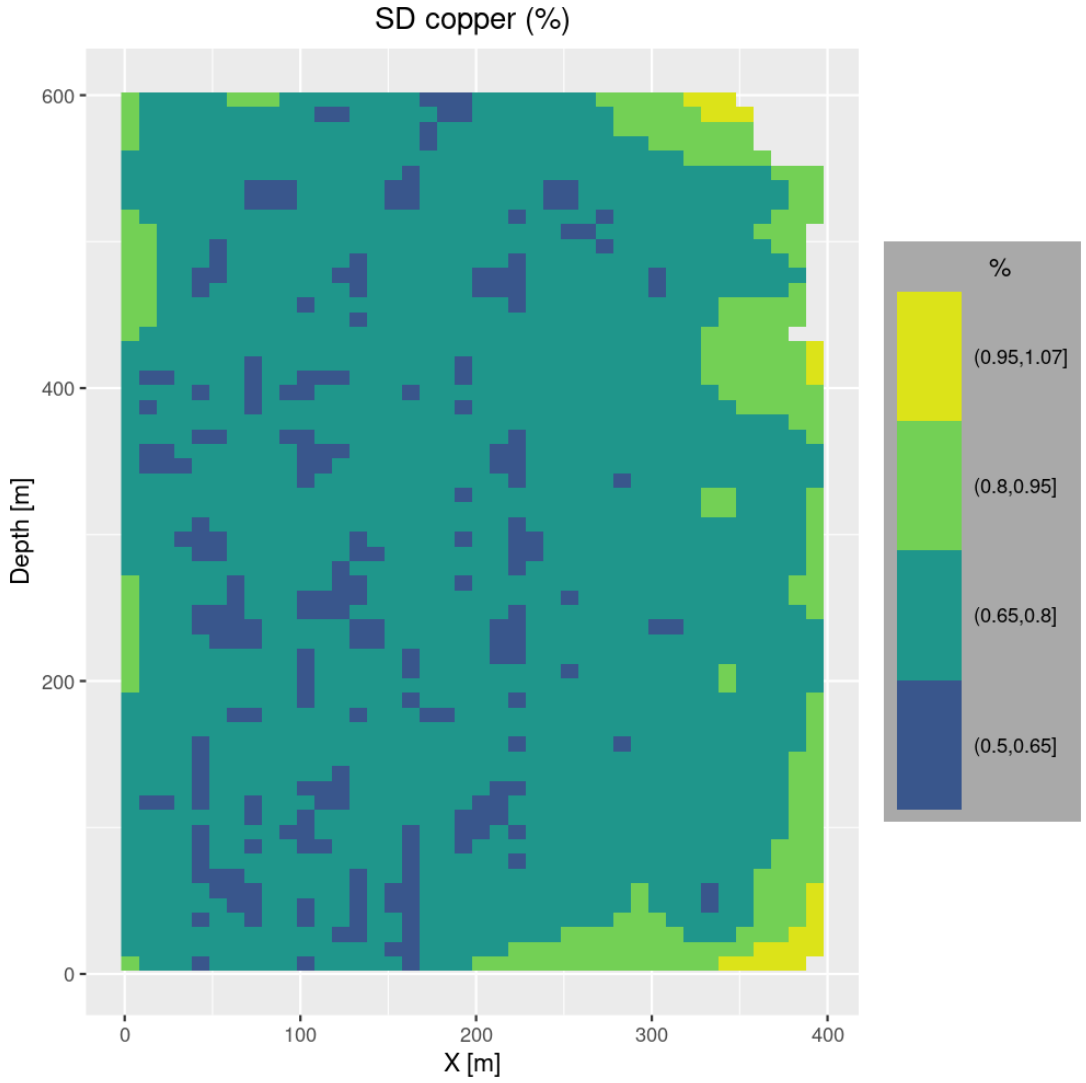
Comparación Kriging de cobre sin transformar (isotrópico) vs. transformados (anisotrópico)

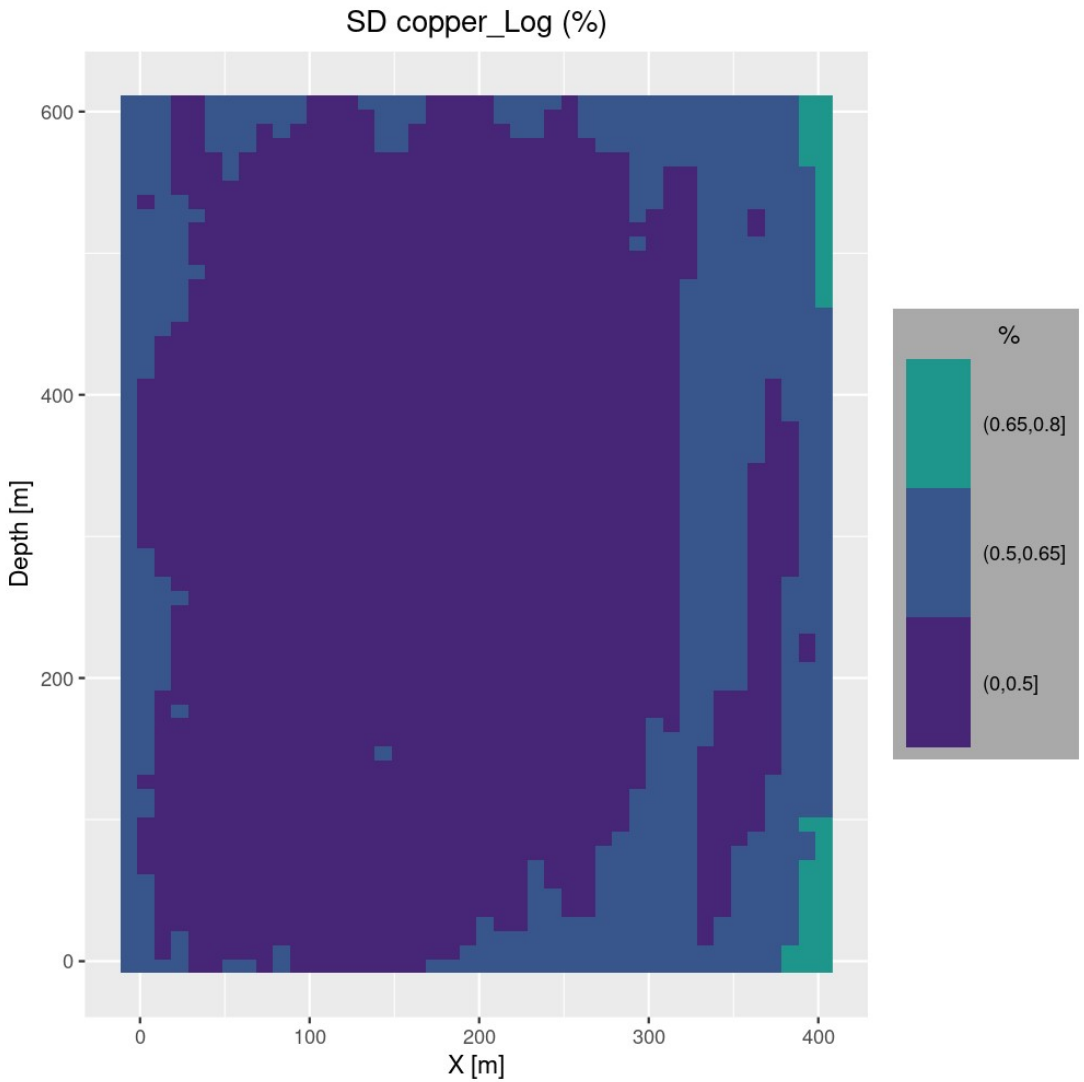




4.1. Estimación espacial univariada

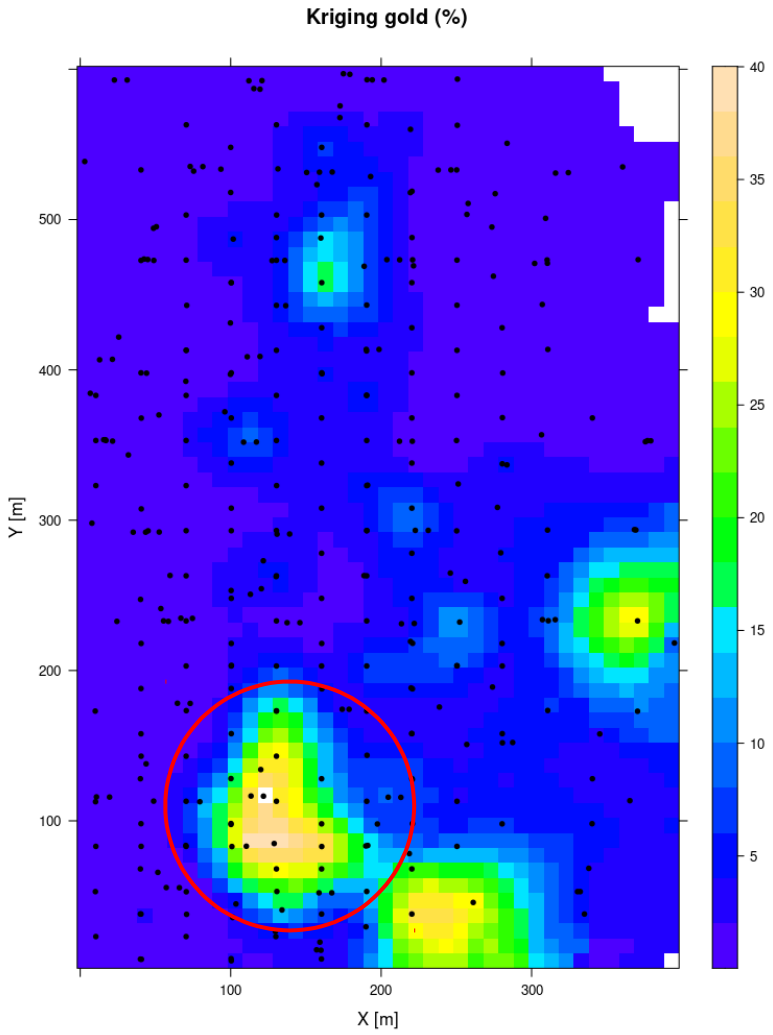
Comparación Kriging de cobre sin transformar (isotrópico) vs. transformados (anisotrópico)

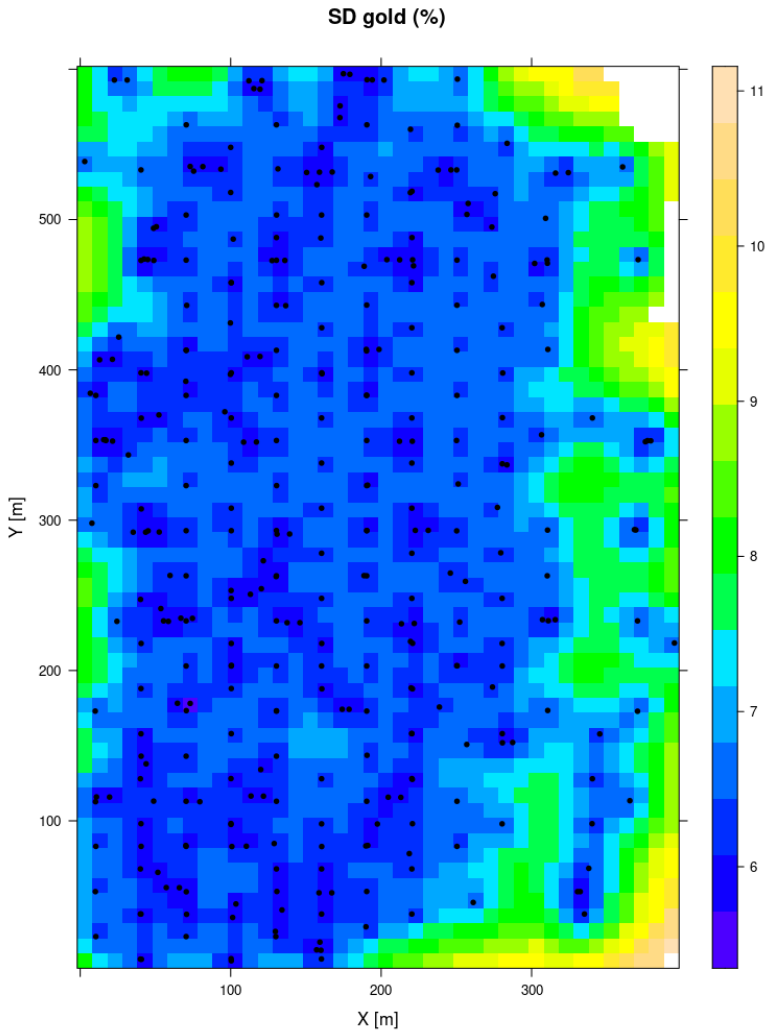


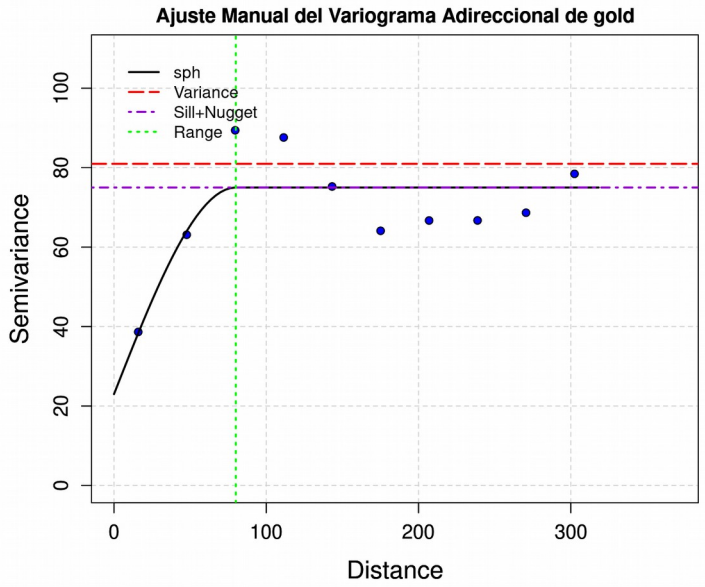


4.1. Estimación espacial univariada

Kriging Ordinario Puntual de oro sin transformar (isotrópico)







Model	Nugget	Sill+Nugget	Range	MSE
sph	23.0000	75.0000	80.0000	675.3694

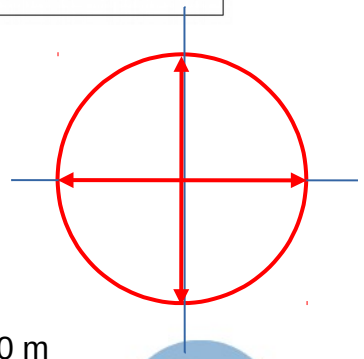
DistMin = 0.1 m

DistMax = 636.7078 m

Malla: 10 m x 10 m

MinPoints = 4

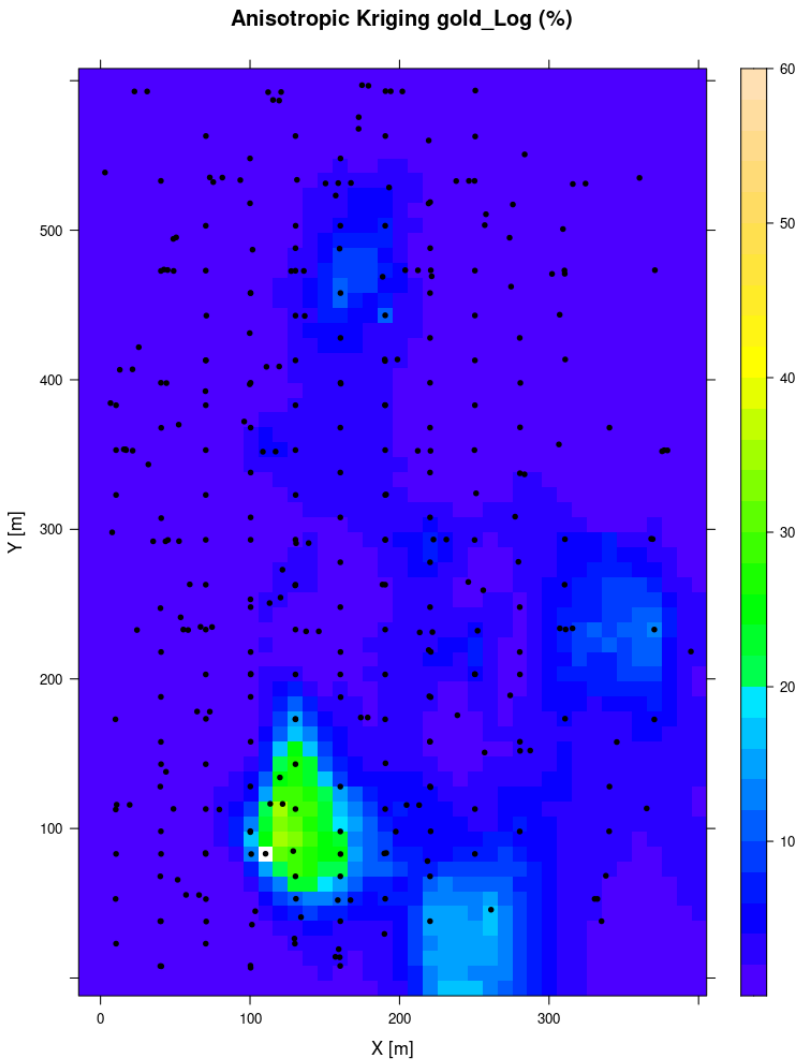
MaxPoints = 10

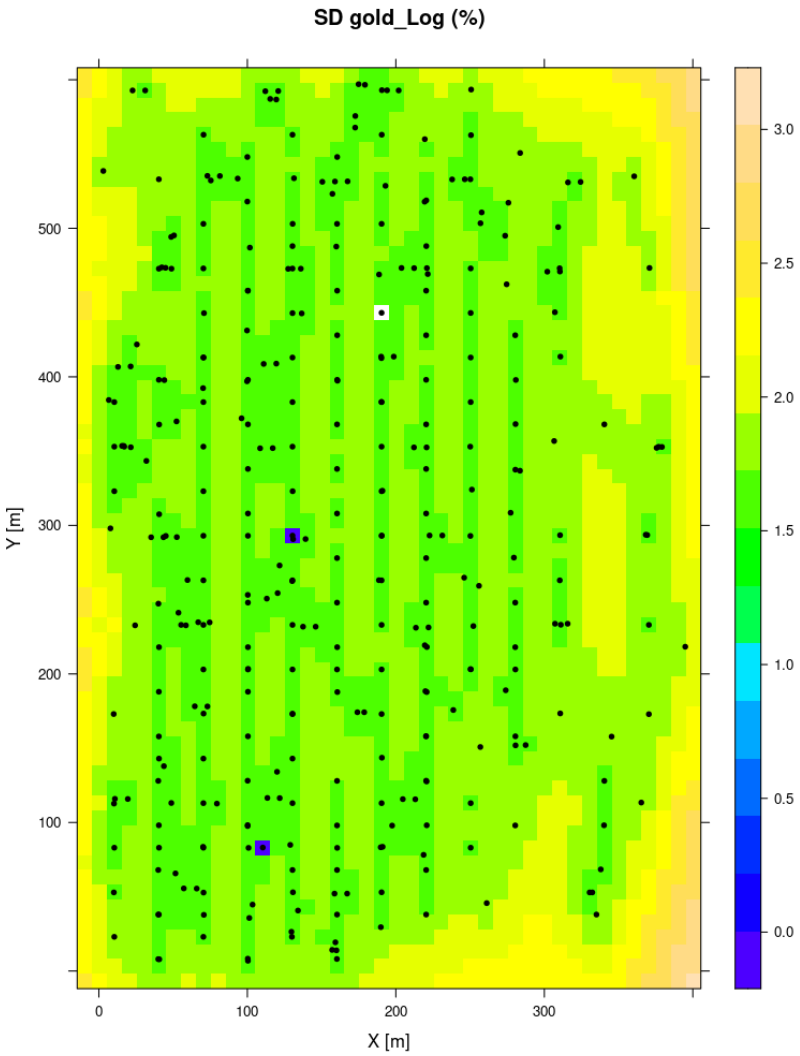


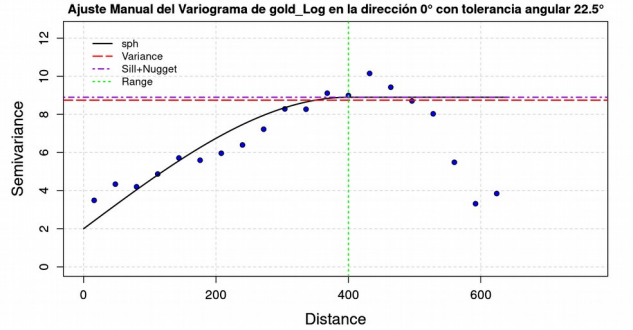
Radio = 80 m

4.1. Estimación espacial univariada

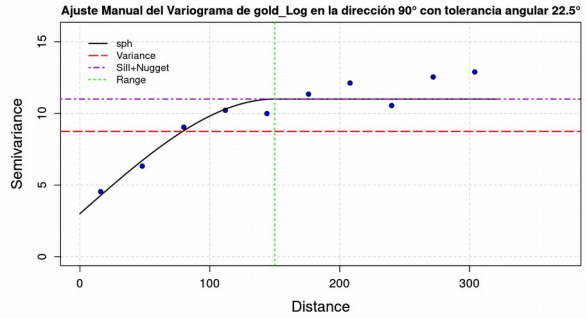
Kriging Ordinario Puntual de oro transformado (anisotrópico)



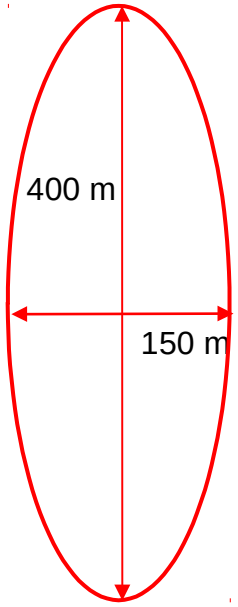




Model	Nugget	Sill+Nugget	Range	MSE
sph	2.0000	8.9000	400.0000	76.6904



Model	Nugget	Sill+Nugget	Range	MSE
sph	3.0000	11.0000	150.0000	8.8009



DistMin = 0.1 m

DistMax = 636.7078 m

Malla: 10 m x 10 m

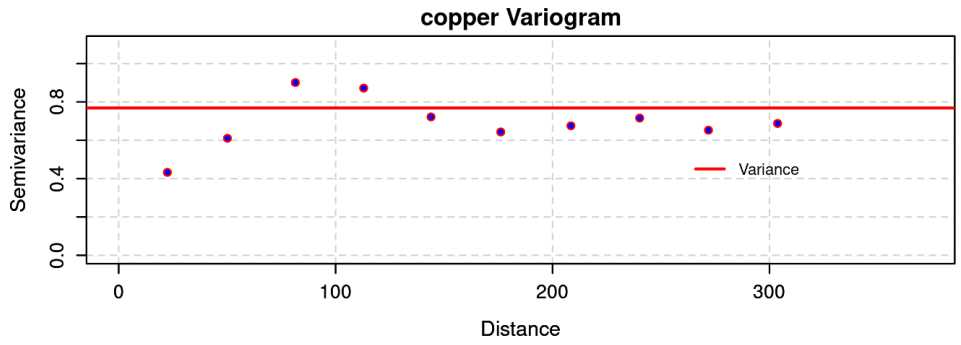
MinPoints = 4

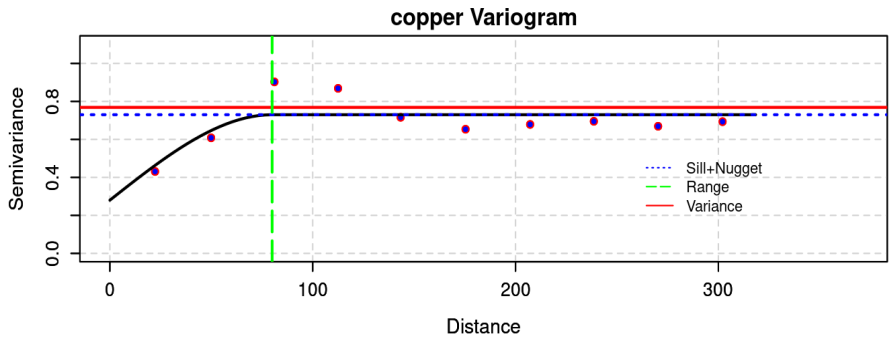
MaxPoints = 10

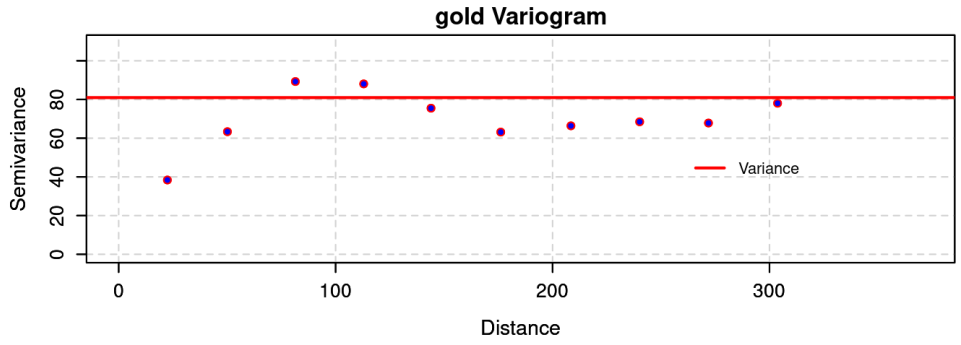
4.2. Estimación espacial conjunta

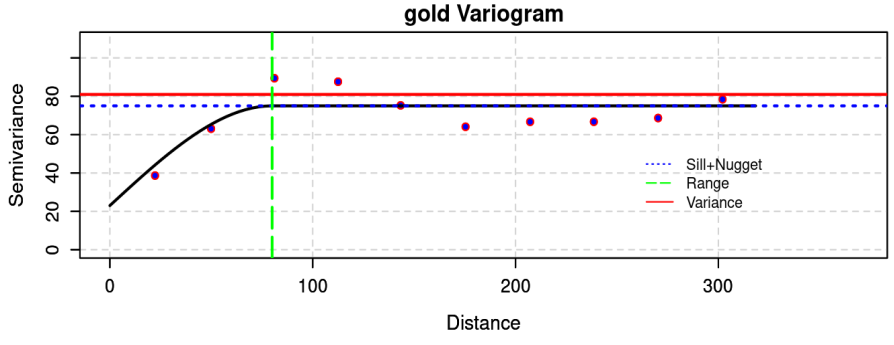
4.2. Estimación espacial conjunta

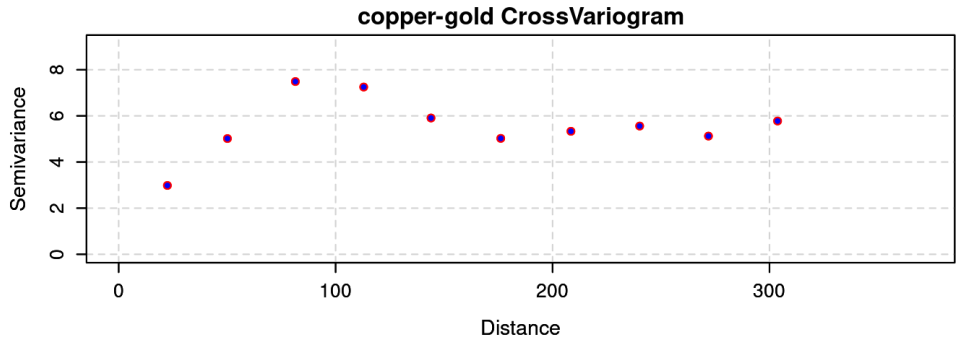
Análisis variográfico conjunto de cobre-oro sin transformar (isotrópico)

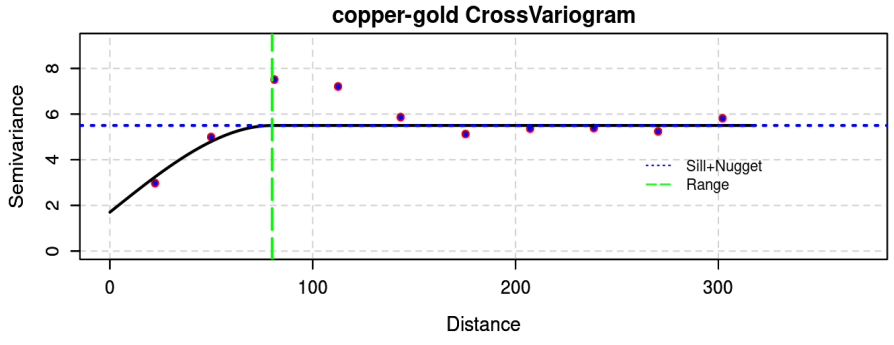












4.2. Estimación espacial conjunta

Modelo de corregionalización lineal de cobre-oro sin transformar (isotrópico)

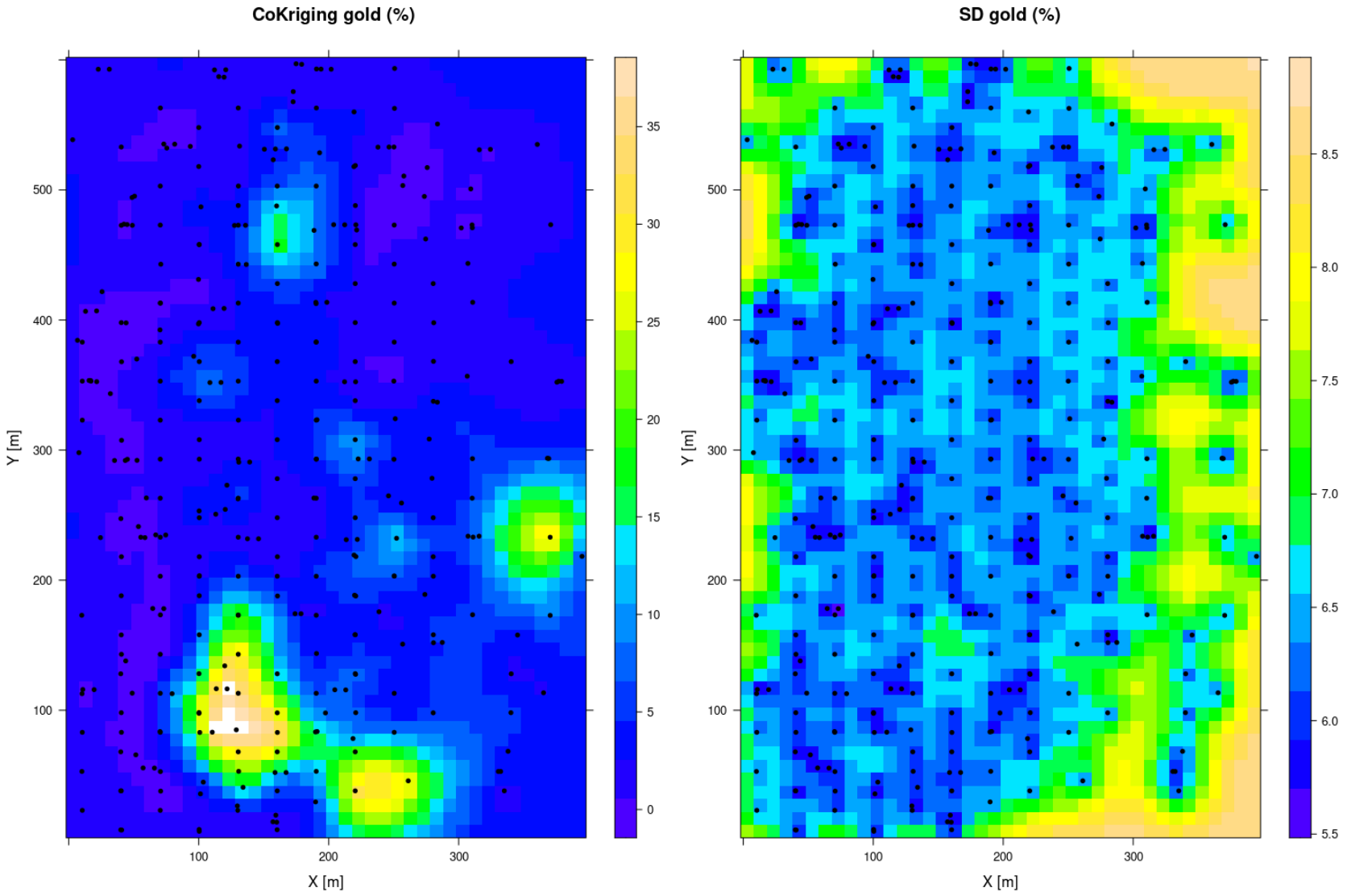
Variables	Modelo	Nugget	Sill-Nugget	Alcance
copper_grade	**Esférico**	**0.28**	**0.45**	**80.00**
gold_grade	**Esférico**	**23**	**52**	**80.00**
copper_grade-gold_grade	**Esférico**	**1.7**	**3.8**	**80.00**

$$23 \times 0.28 - 1.7^2 = 3.55 > 0$$

$$52 \times 0.45 - 3.8^2 = 8.96 > 0$$

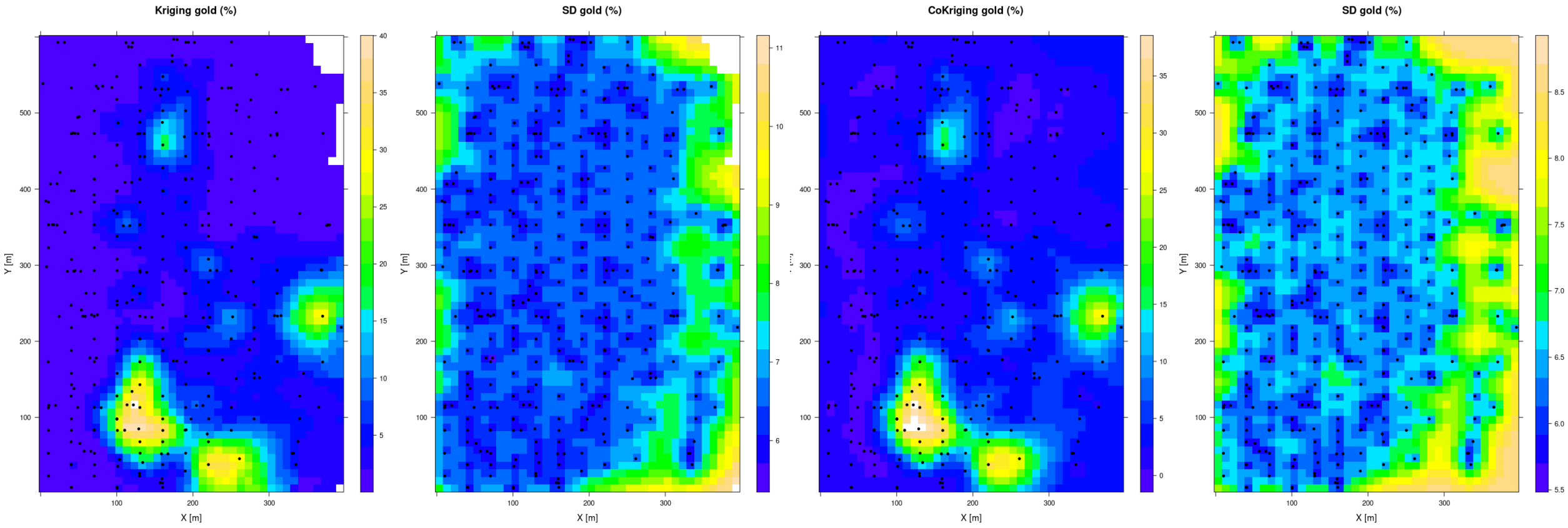
4.2. Estimación espacial conjunta

CoKriging Ordinario Puntual de oro sin transformar (isotrópico)



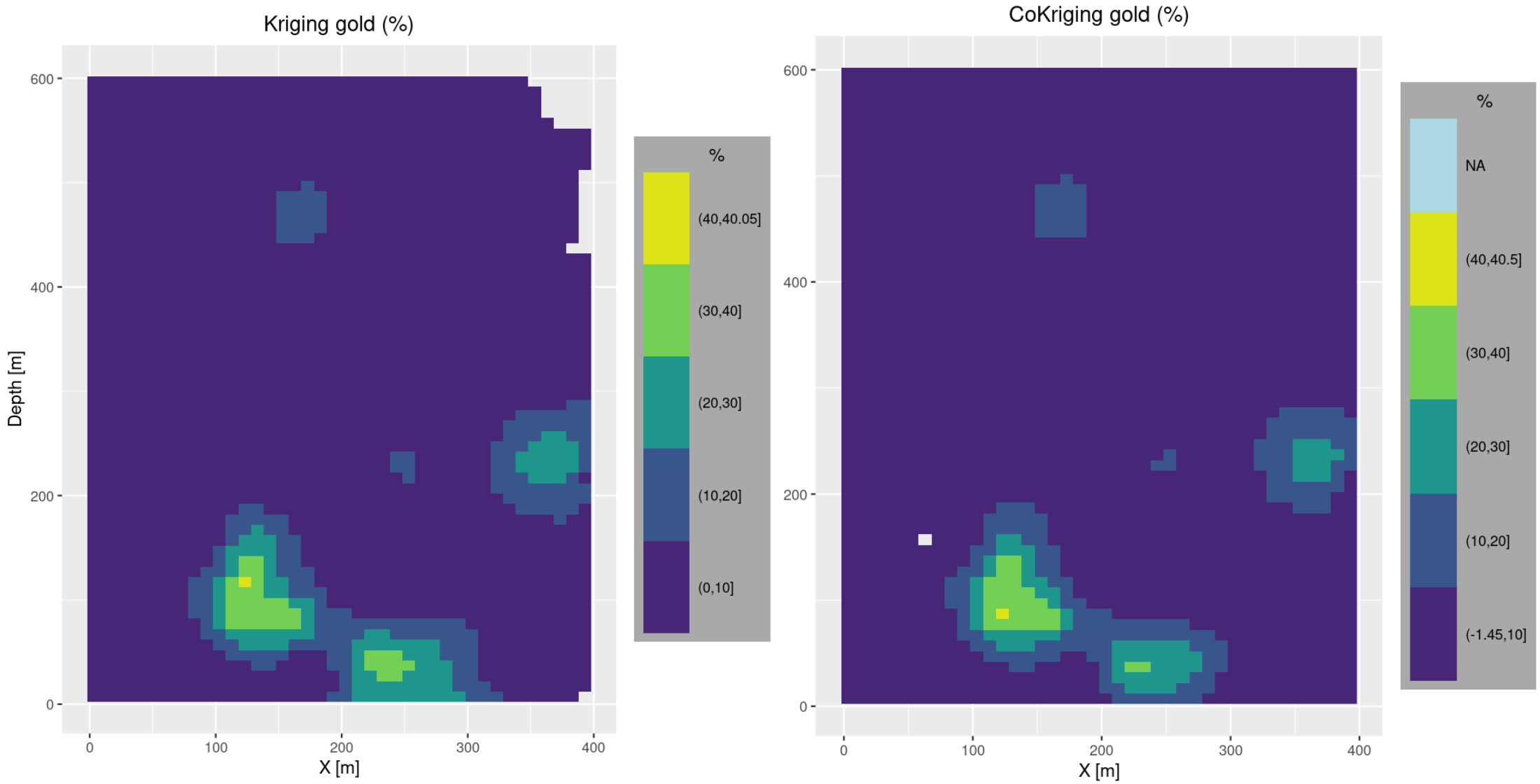
4.2. Estimación espacial conjunta

Comparación de Kriging vs. CoKriging de oro sin transformar (isotrópico)



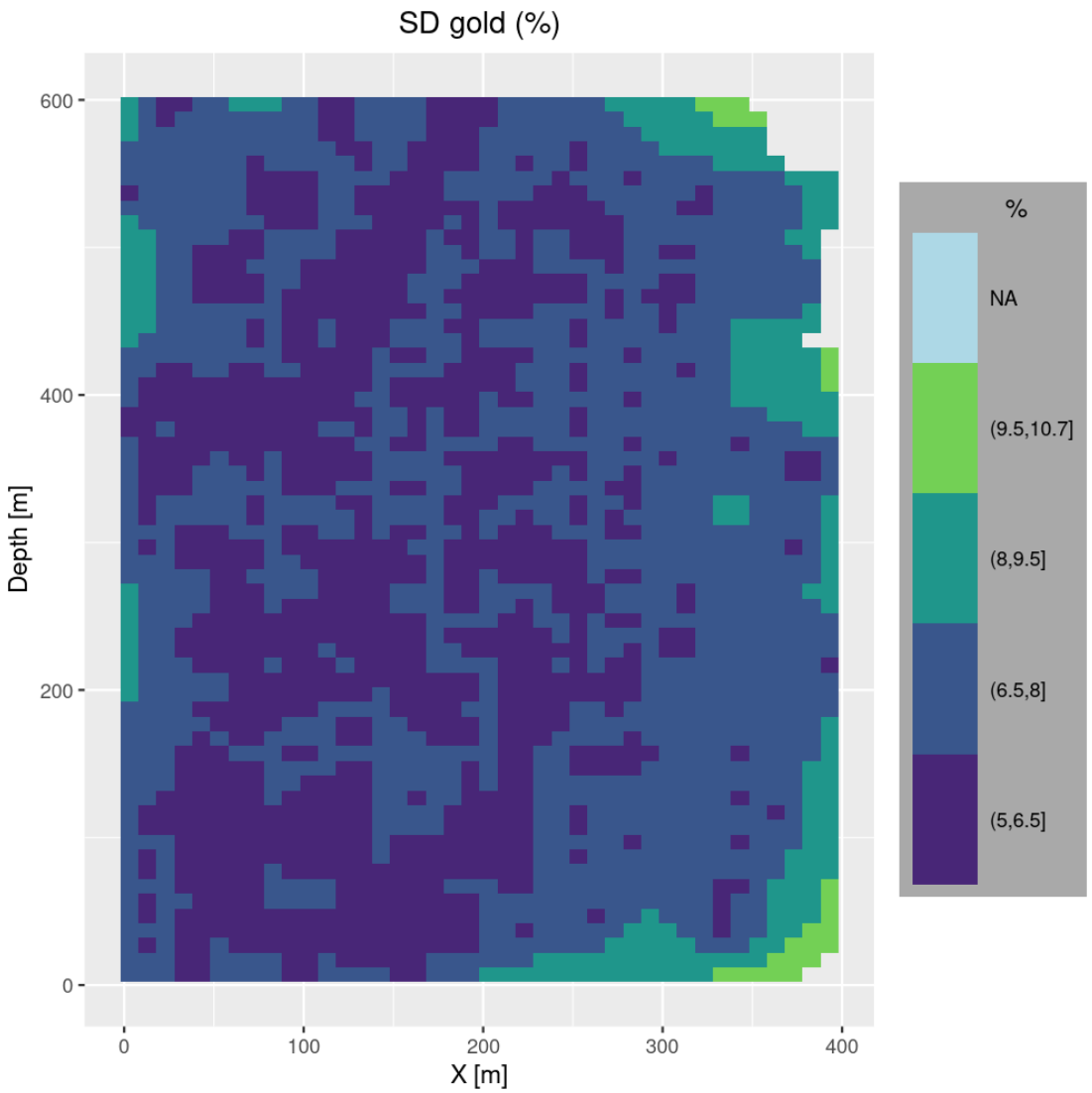
4.2. Estimación espacial conjunta

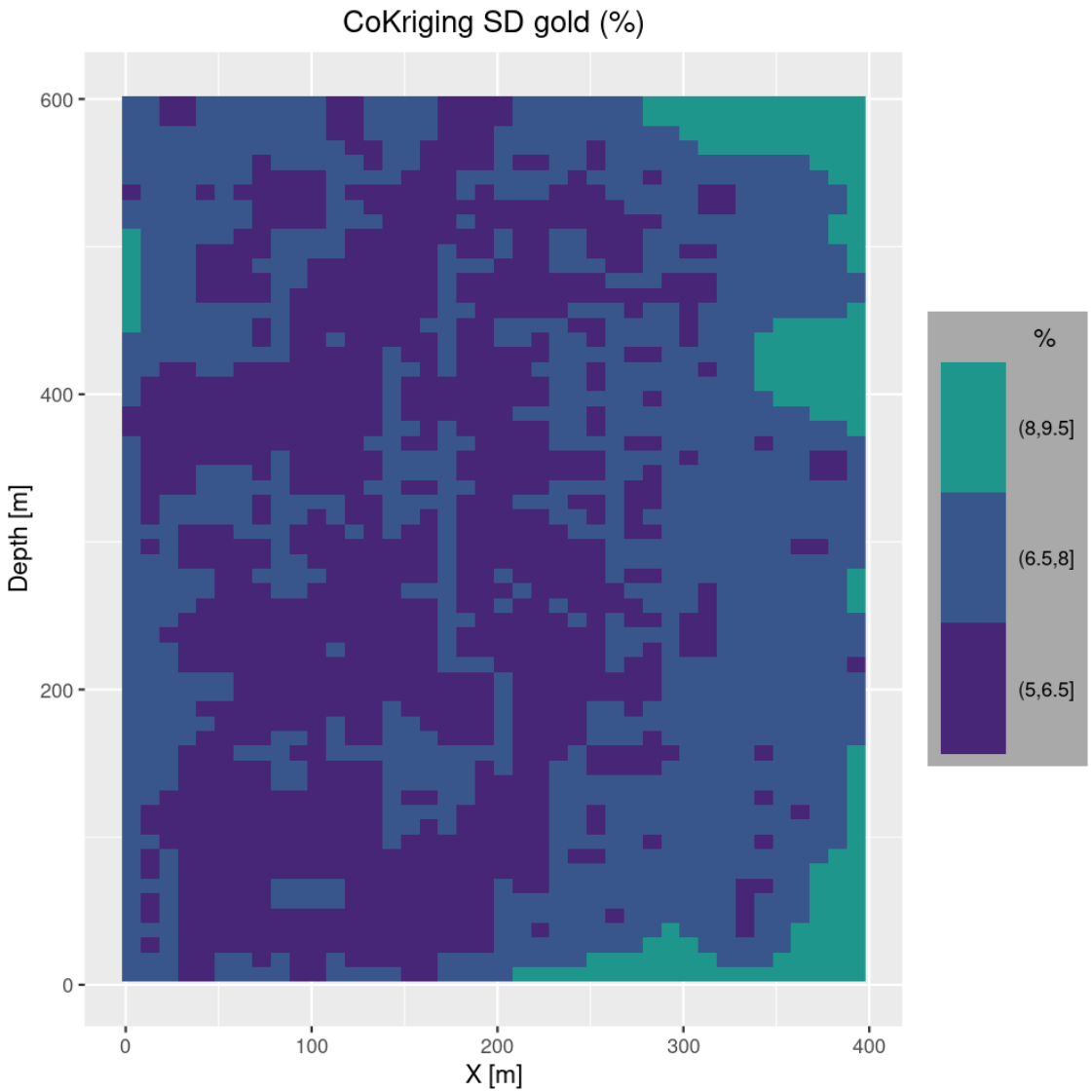
Comparación de Kriging vs. CoKriging de oro sin transformar (isotrópico)



4.2. Estimación espacial conjunta

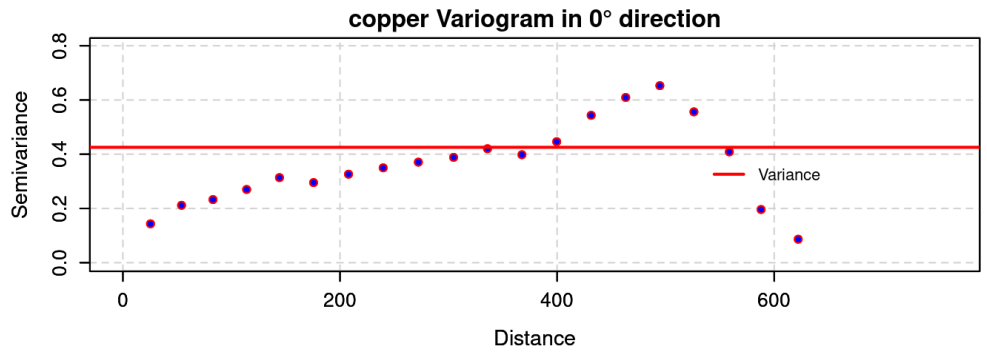
Comparación de Kriging vs. CoKriging de oro sin transformar (isotrópico)

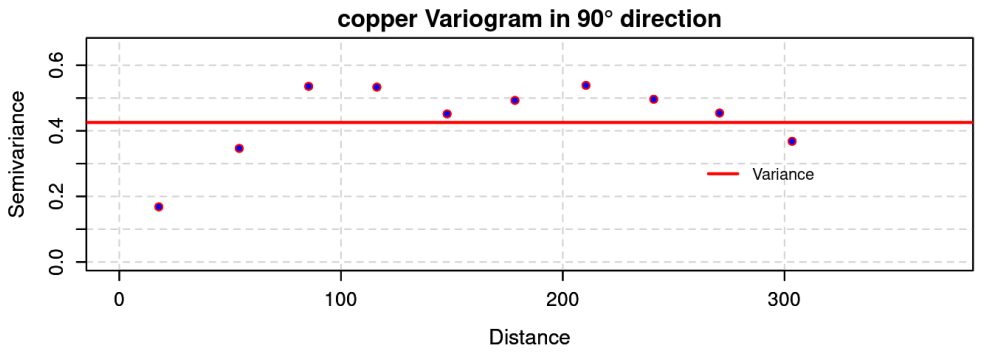


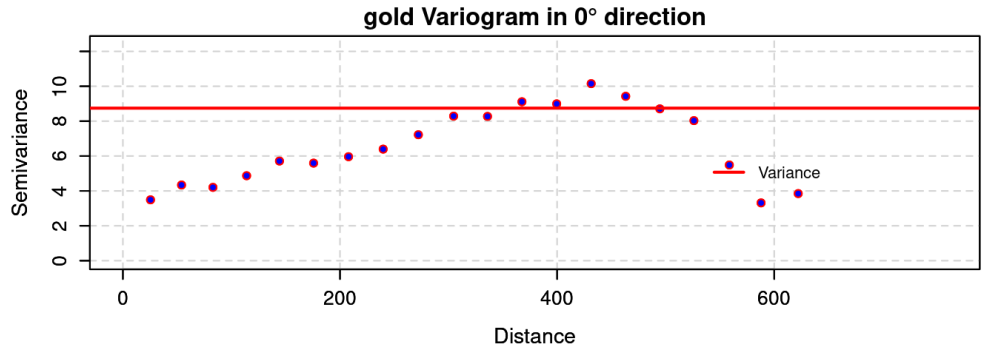


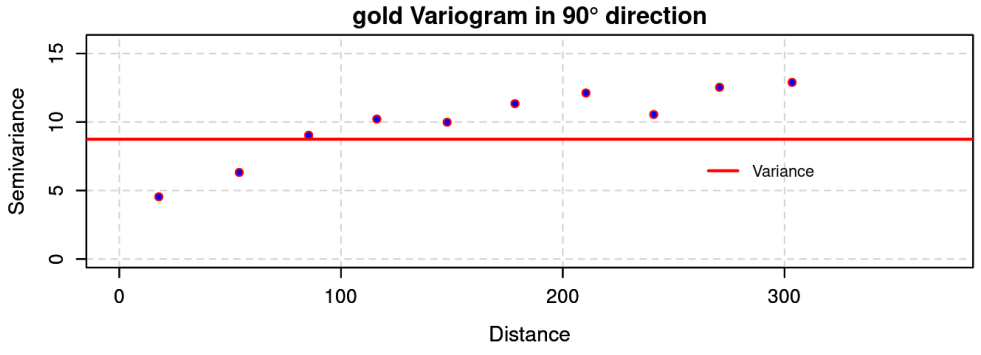
4.2. Estimación espacial conjunta

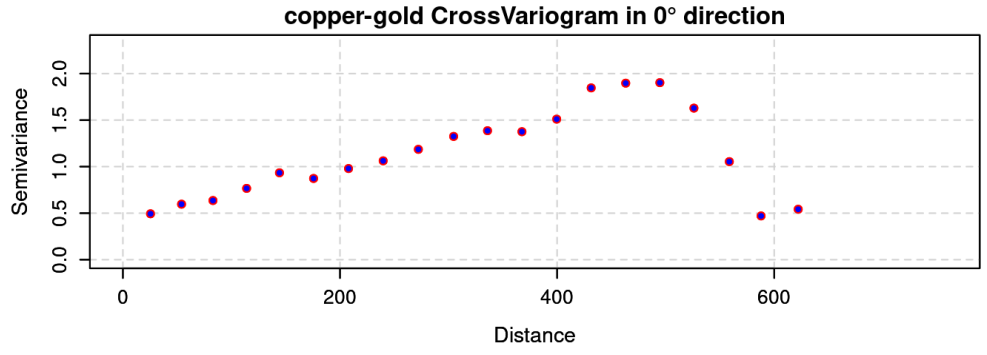
Análisis variográfico conjunto de cobre-oro transformados (anisotrópico)

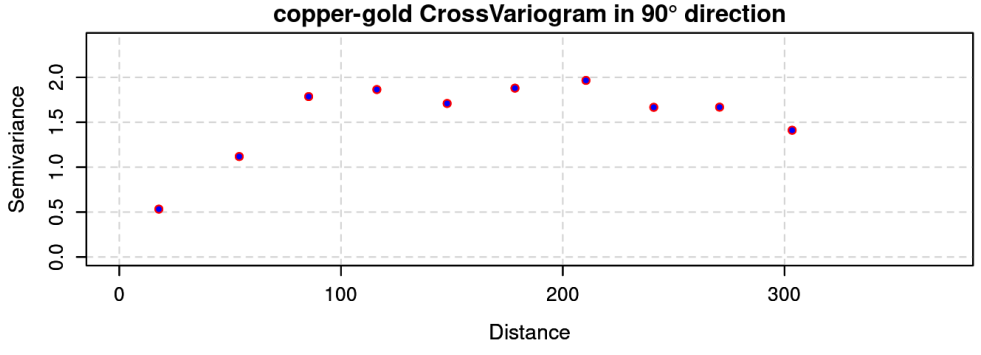






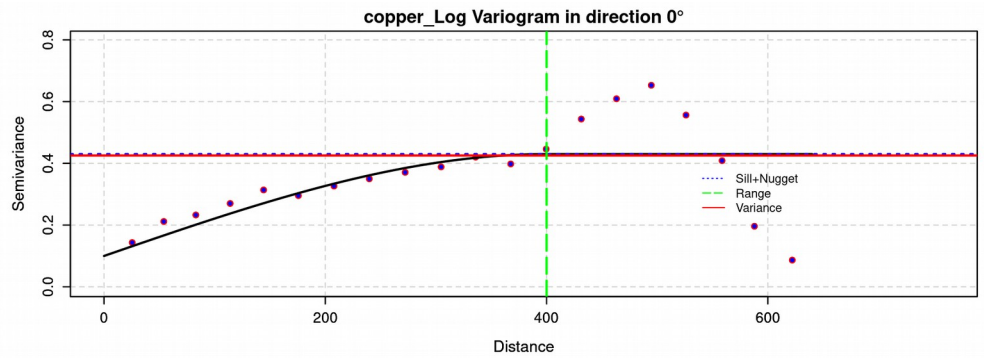


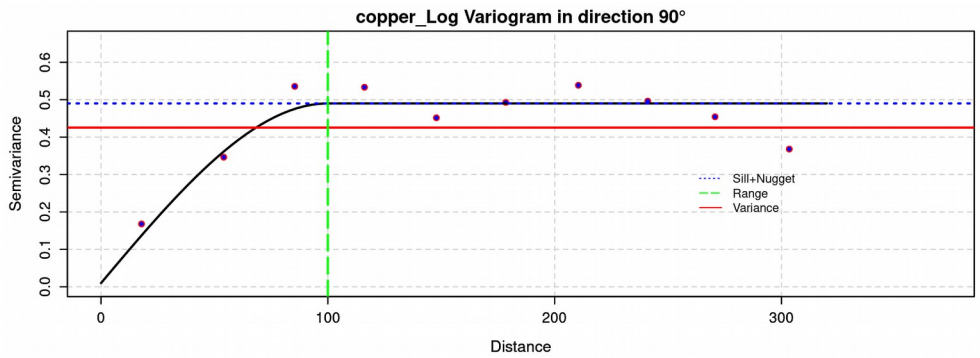


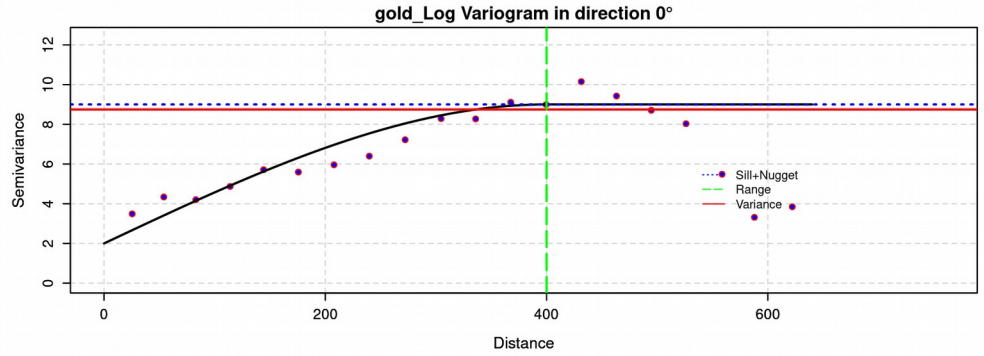


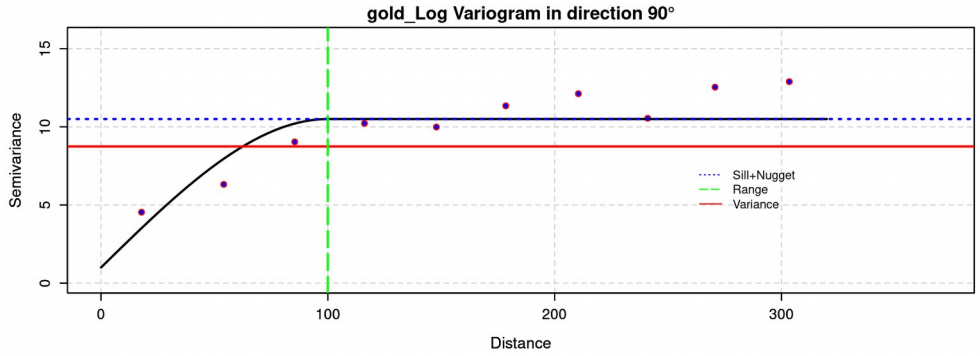
4.2. Estimación espacial conjunta

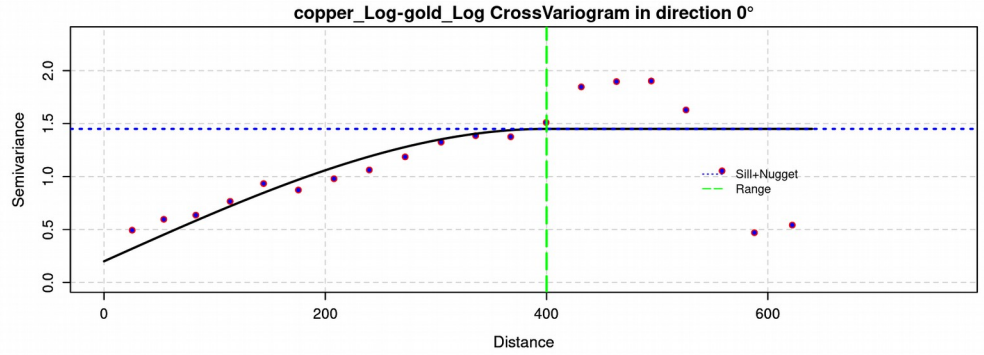
Análisis variográfico conjunto de cobre-oro transformados (anisotrópico)

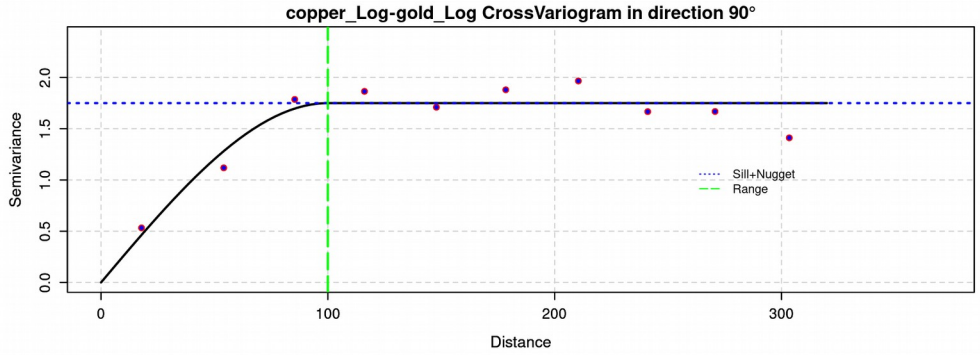












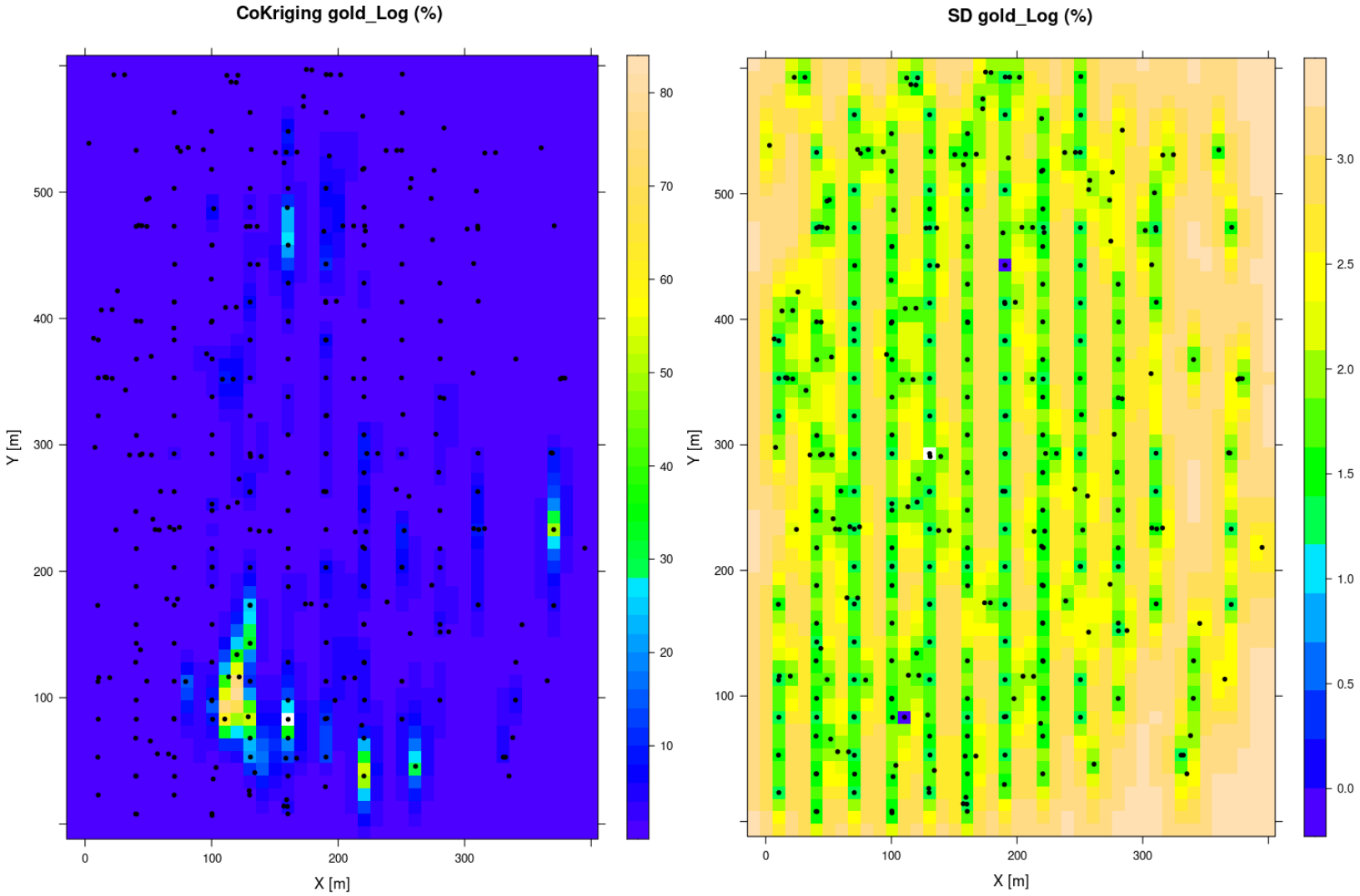
4.2. Estimación espacial conjunta

Modelo de corregionalización lineal de cobre-oro transformados (anisotrópico)

0°	Variables	Modelo	Nugget	Sill-Nugget	Alcance
	copper_Log_grade	**Esférico**	**0.15**	**0.42**	**400.00**
	gold_Log_grade	**Esférico**	**2.00**	**8.90**	**400.00**
	copper_Log_grade-gold_Log_grade	**Esférico**	**0.20**	**1.25**	**400.00**
90°	**Variables**	**Modelo**	**Nugget**	**Sill-Nugget**	**Alcance**
	copper_Log_grade	**Esférico**	**0.01**	**0.48**	**100**
	gold_Log_grade	**Esférico**	**1.00**	**9.5**	**100**
	copper_Log_grade-gold_Log_grade	**Esférico**	**0.00**	**1.75**	**100**

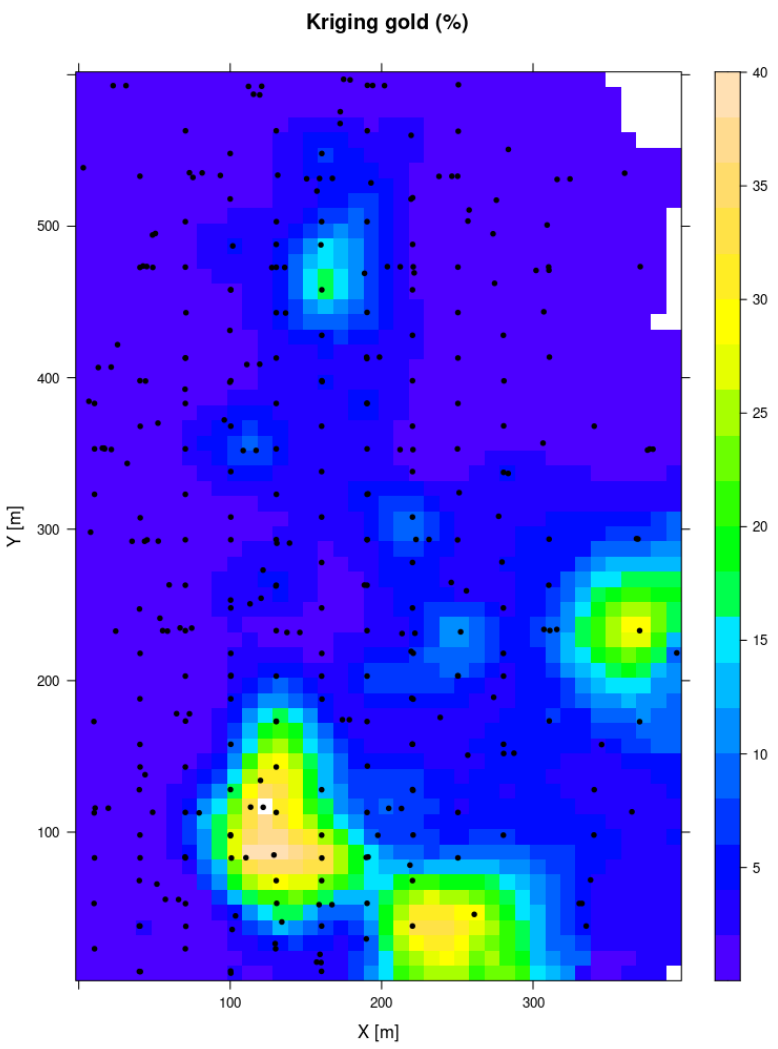
4.2. Estimación espacial conjunta

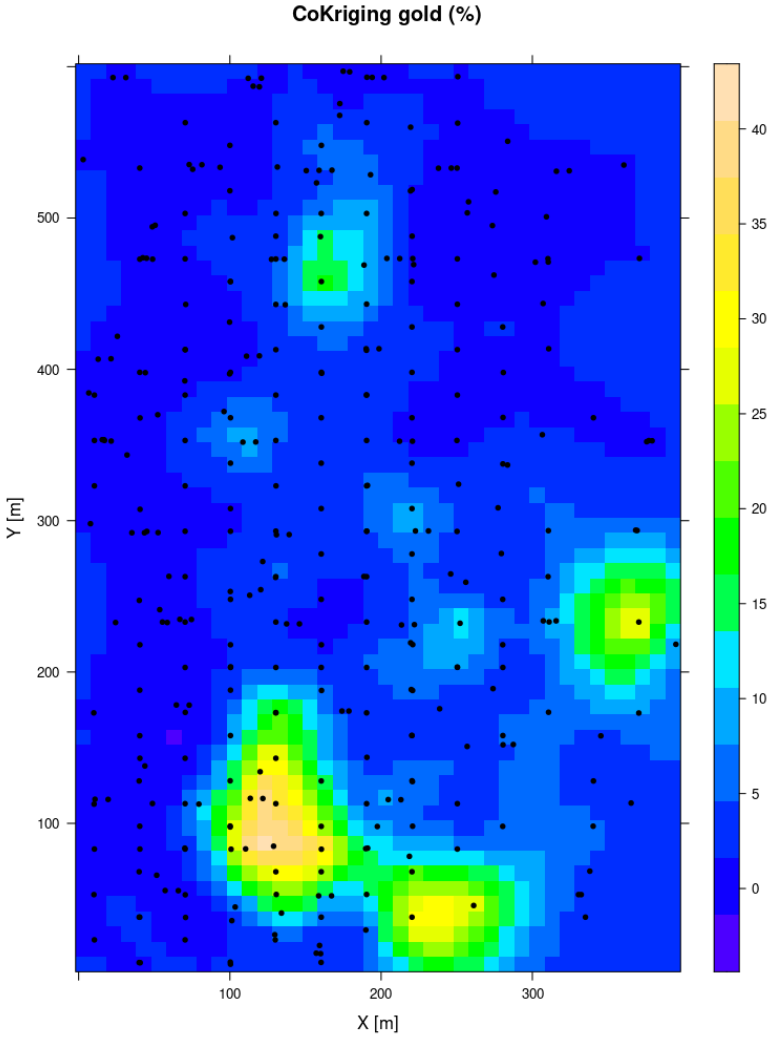
CoKriging Ordinario Puntual de oro transformado (anisotrópico)

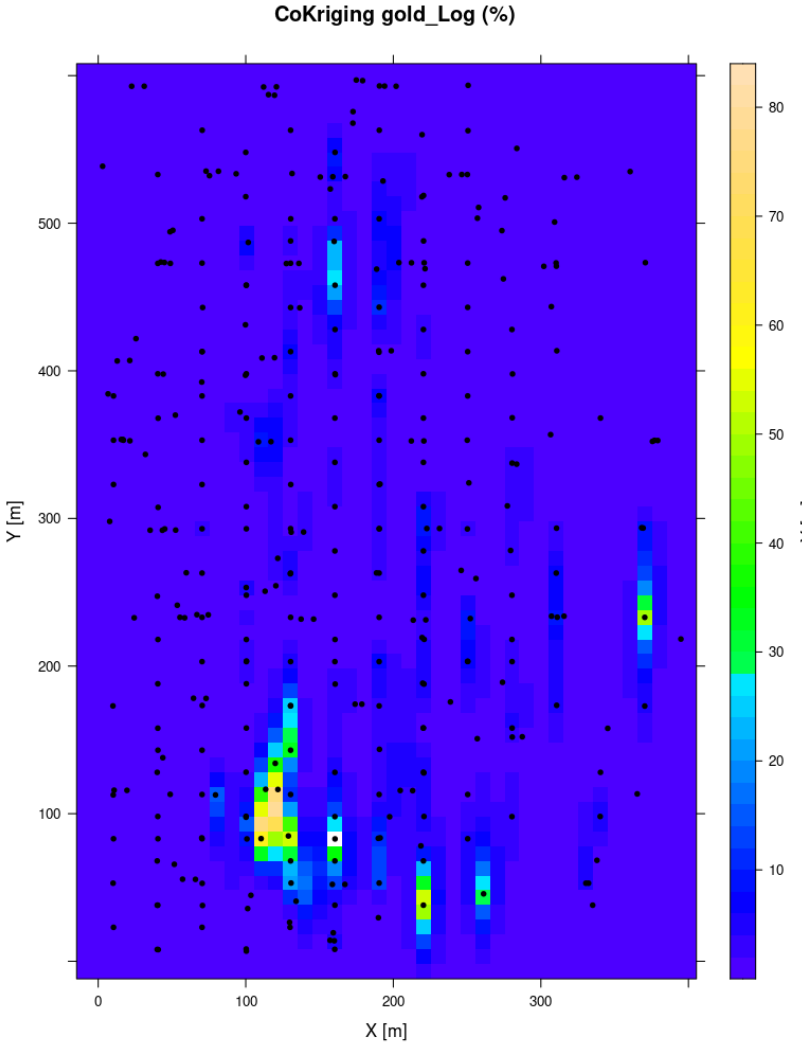


4.2. Estimación espacial conjunta

Kriging y CoKriging de oro sin transformar (isotrópico) y CoKriging de oro transformado (anisotrópico)

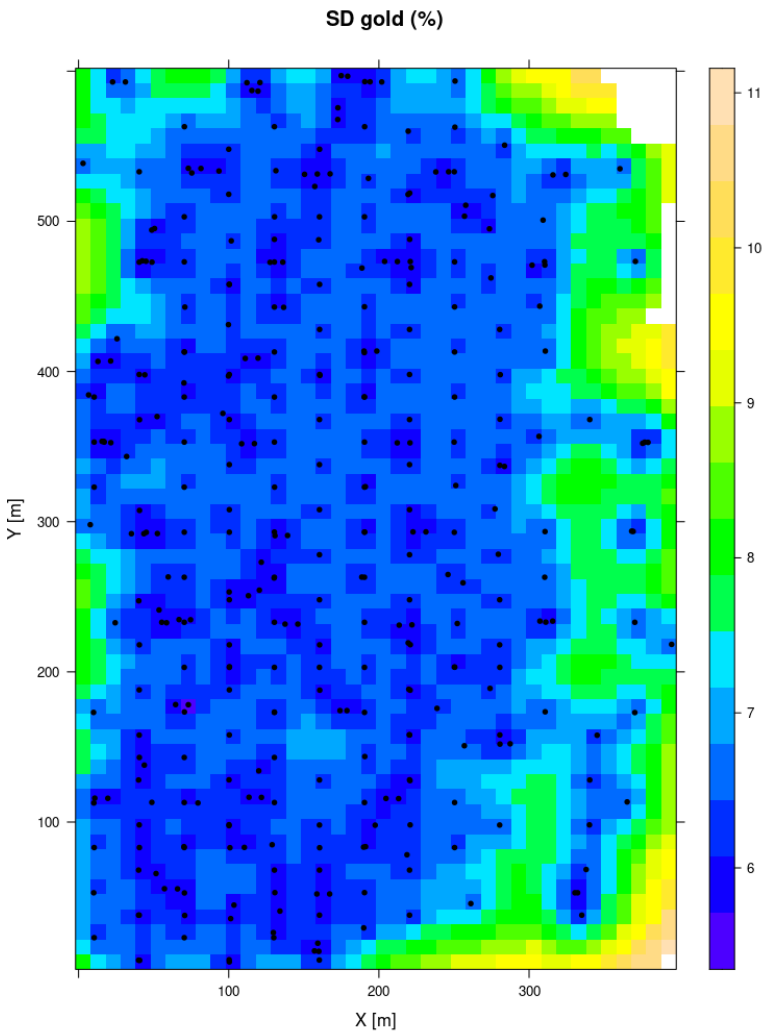


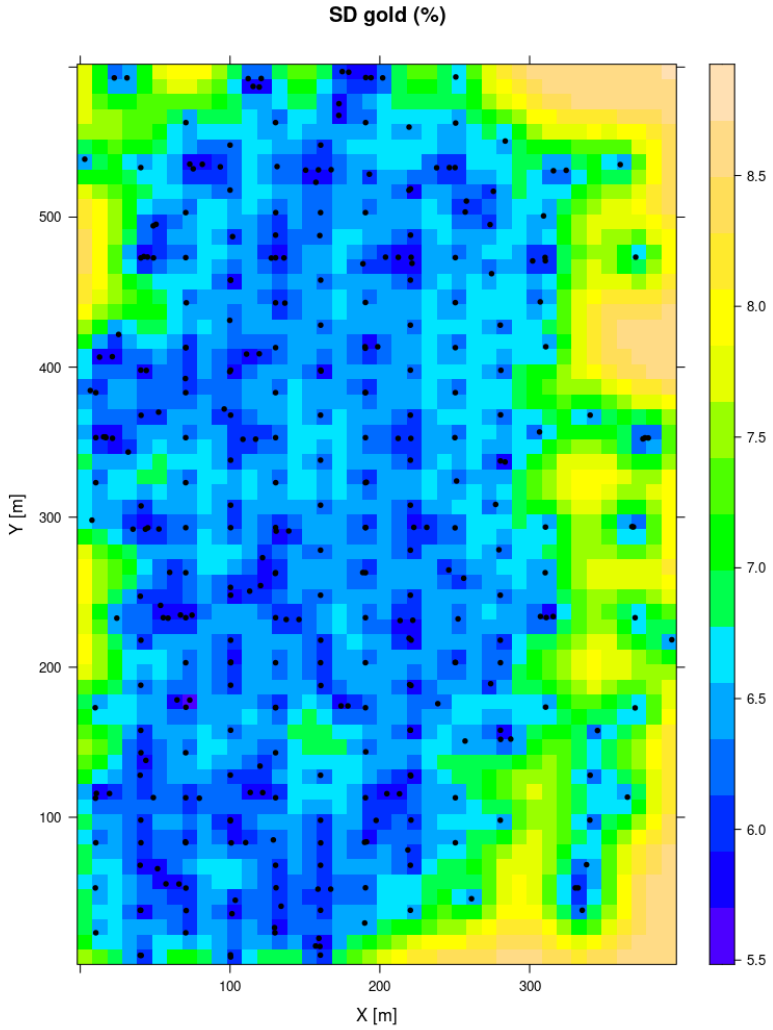


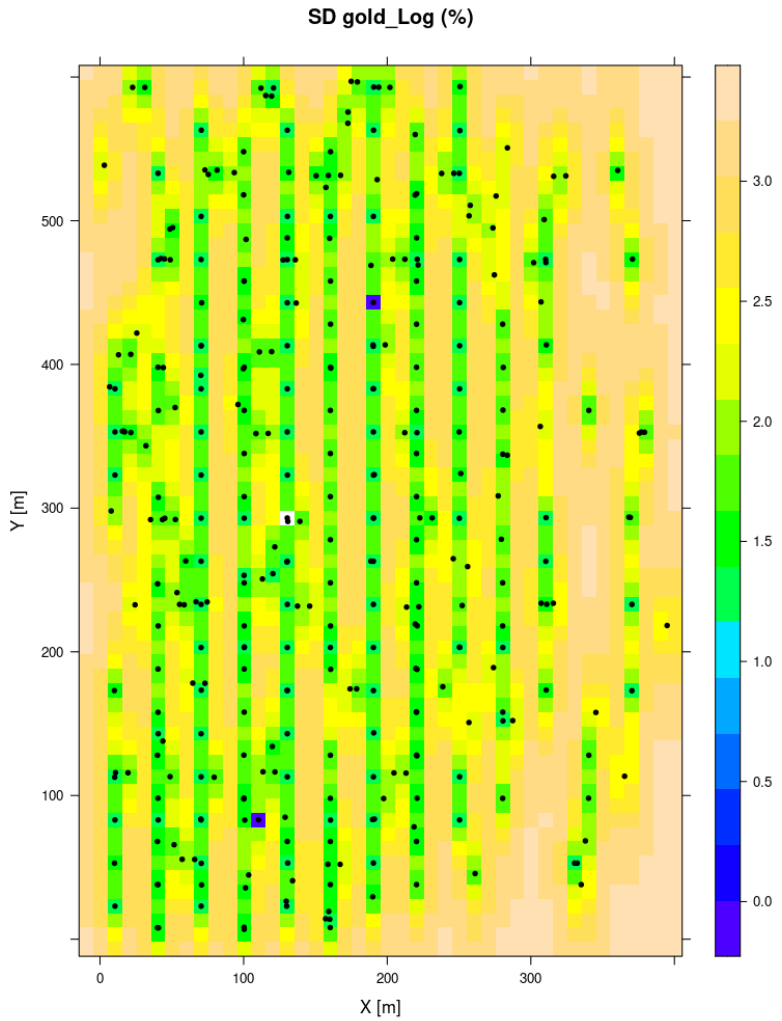


4.2. Estimación espacial conjunta

Kriging y CoKriging de oro sin transformar (isotrópico) y CoKriging de oro transformado (anisotrópico)

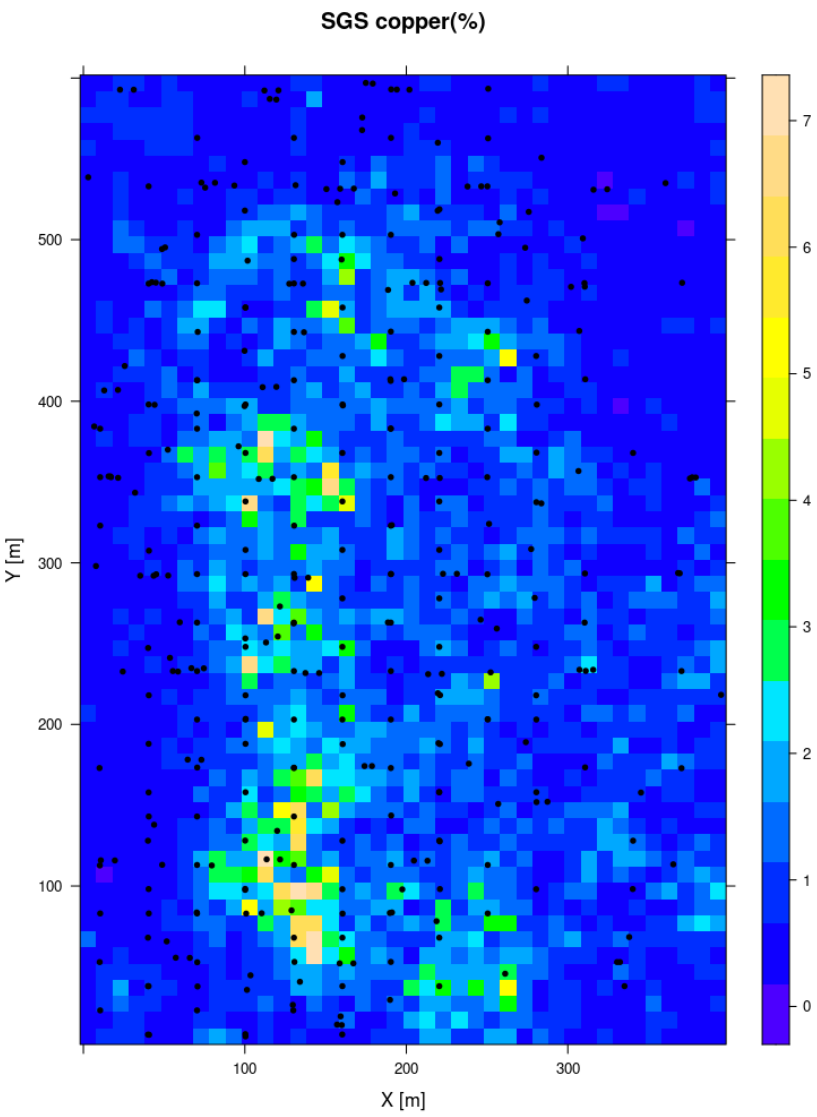


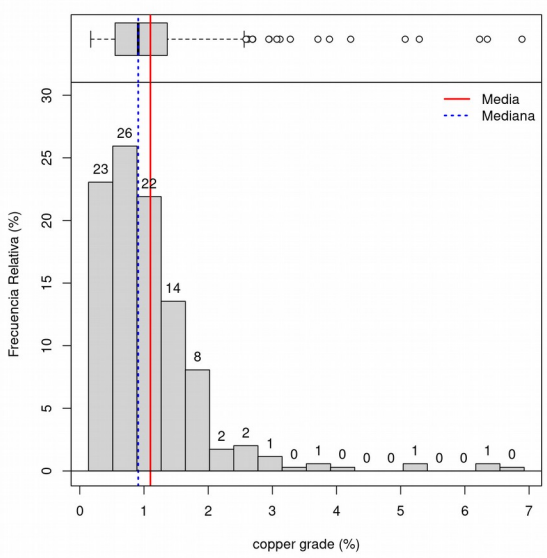


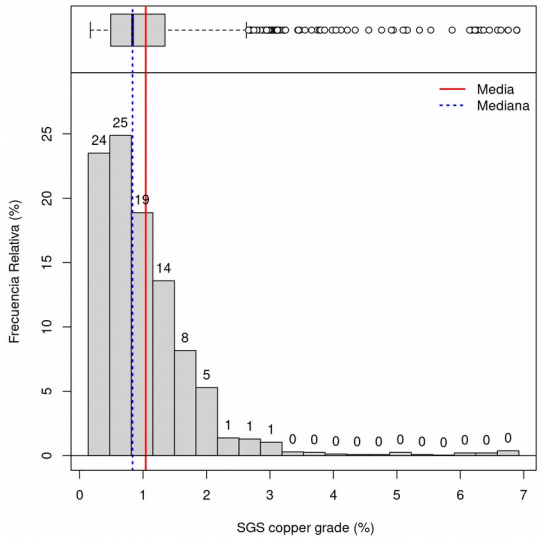


5. Simulación espacial

5.1. Simulación Secuencial Gaussiana

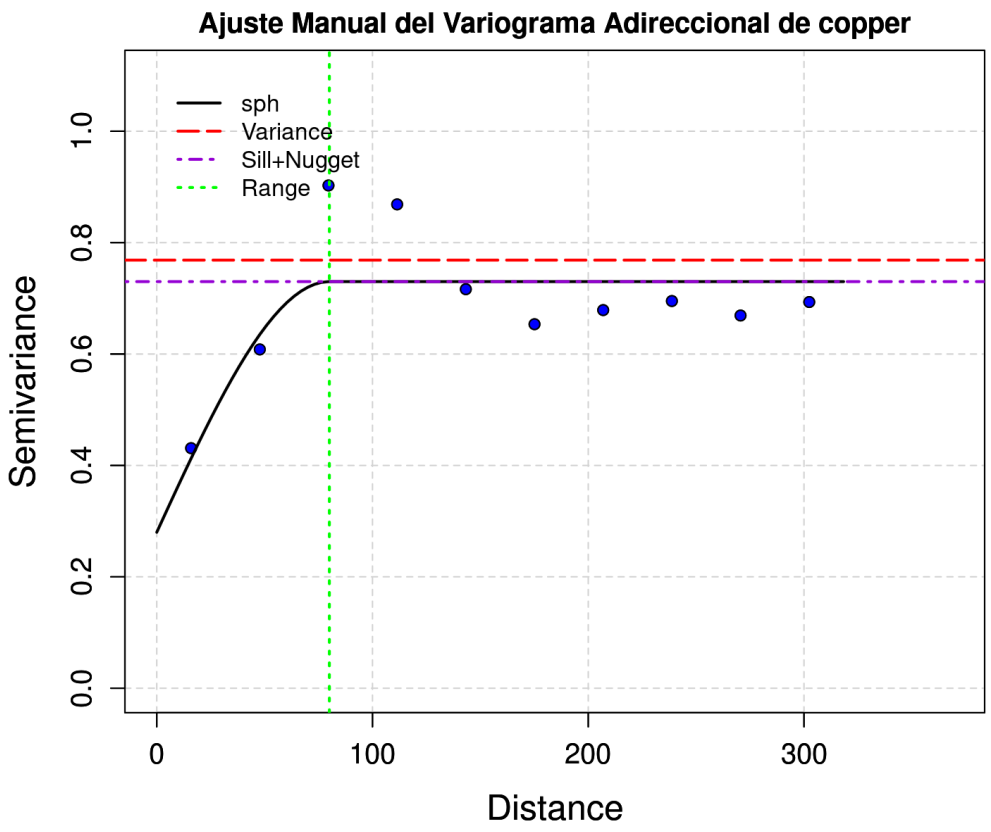




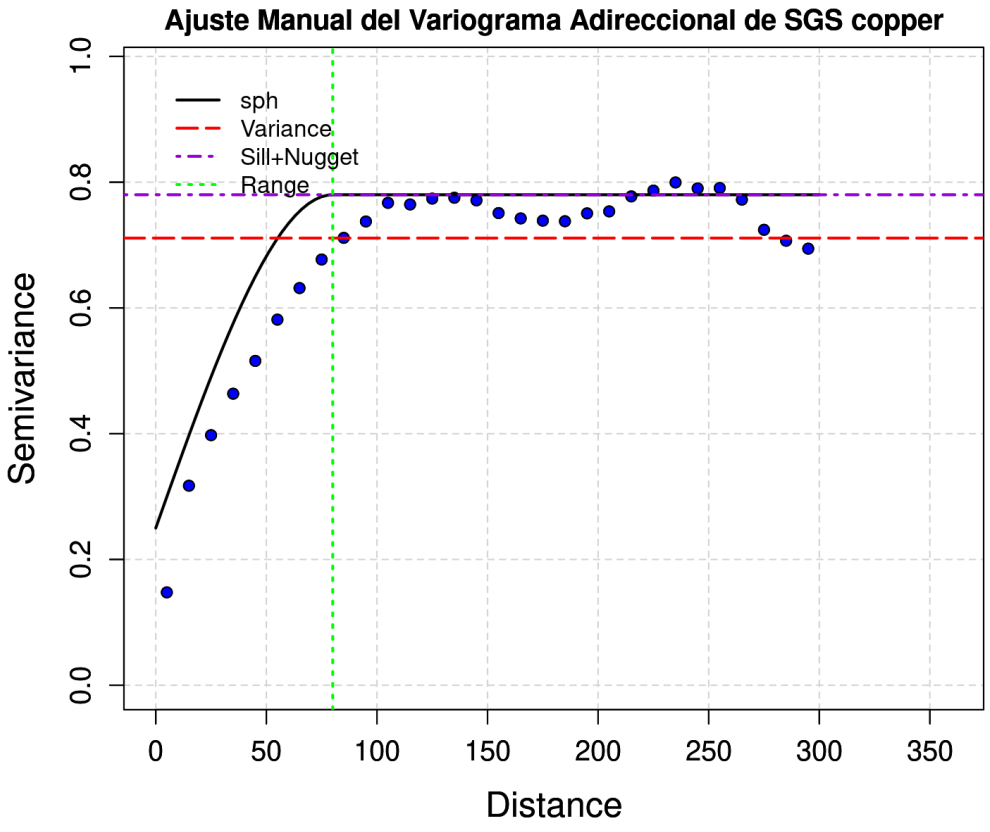


Estadística	Data copper	SGS copper
No_muestras	347	2400
Minimo	0.17	0.17
Cuartil_1er	0.55	0.49
Mediana	0.91	0.83
Media	1.10	1.04
Cuartil_3er	1.36	1.35
Maximo	6.89	6.89
Rango	6.72	6.72
Rango_Intercuartil	0.81	0.86
Varianza	0.77	0.71
Desv_Estandar	0.88	0.84
Simetria	3.11	3.19
Curtosis	17.12	18.61

5.1. Simulación Secuencial Gaussiana

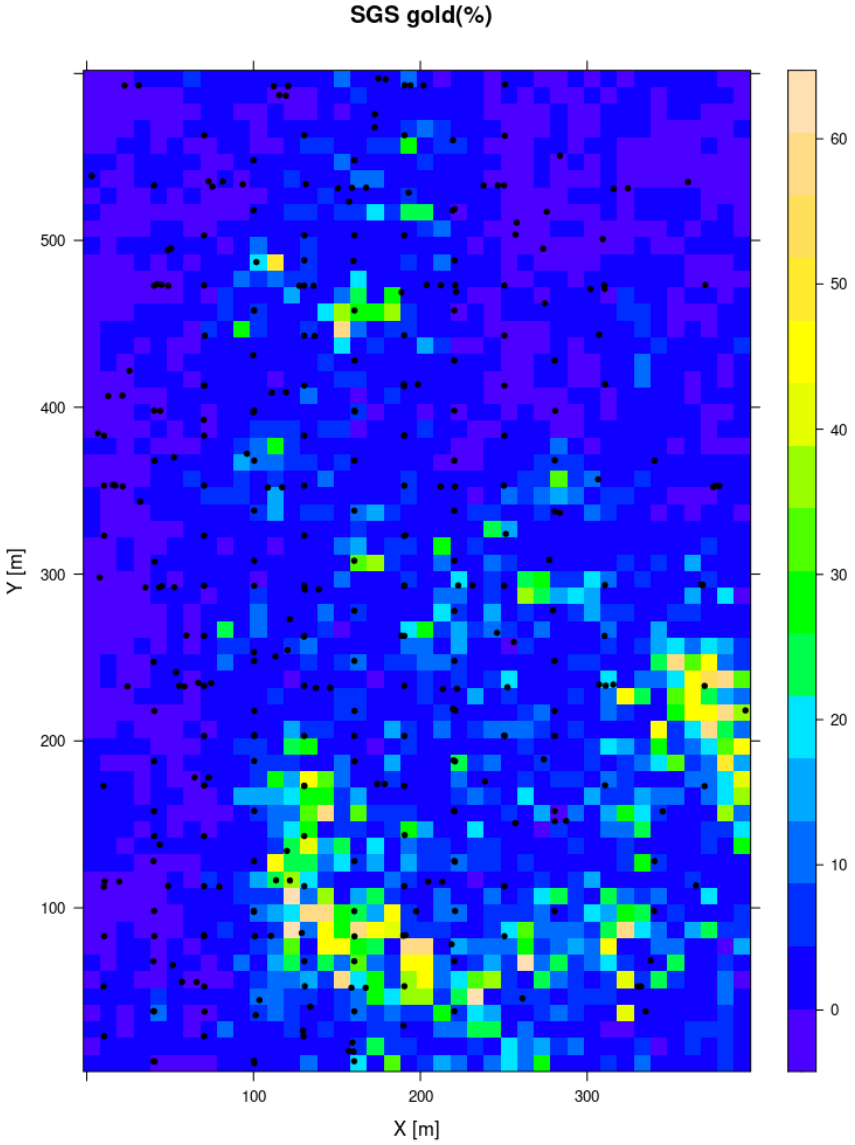


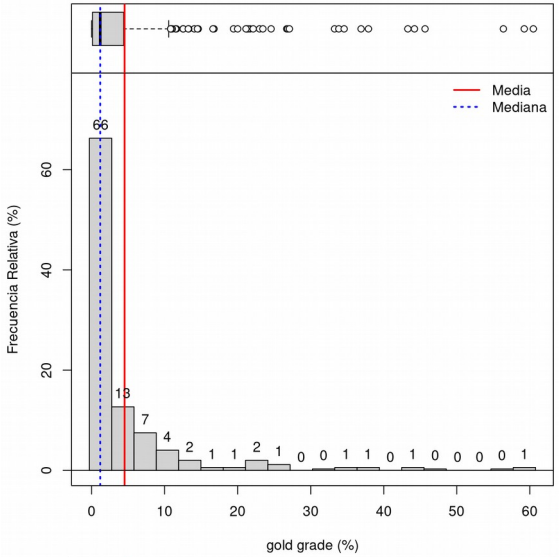
Model	Nugget	Sill+Nugget	Range	MSE
sph	0.2800	0.7300	80.0000	0.0650

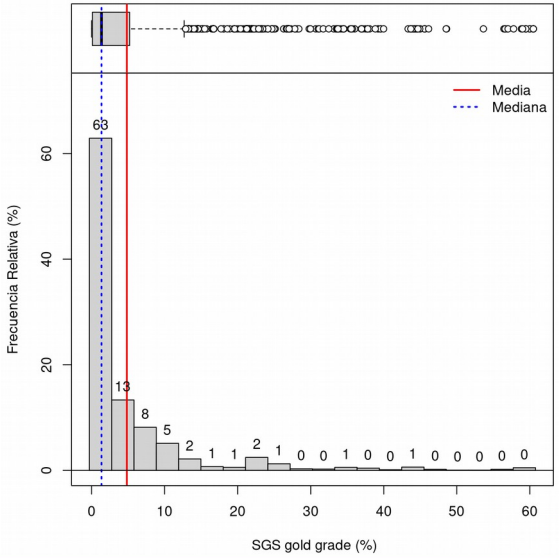


Model	Nugget	Sill+Nugget	Range	MSE
sph	0.2500	0.7800	80.0000	0.1412

5.2. Simulación Secuencial Gaussiana

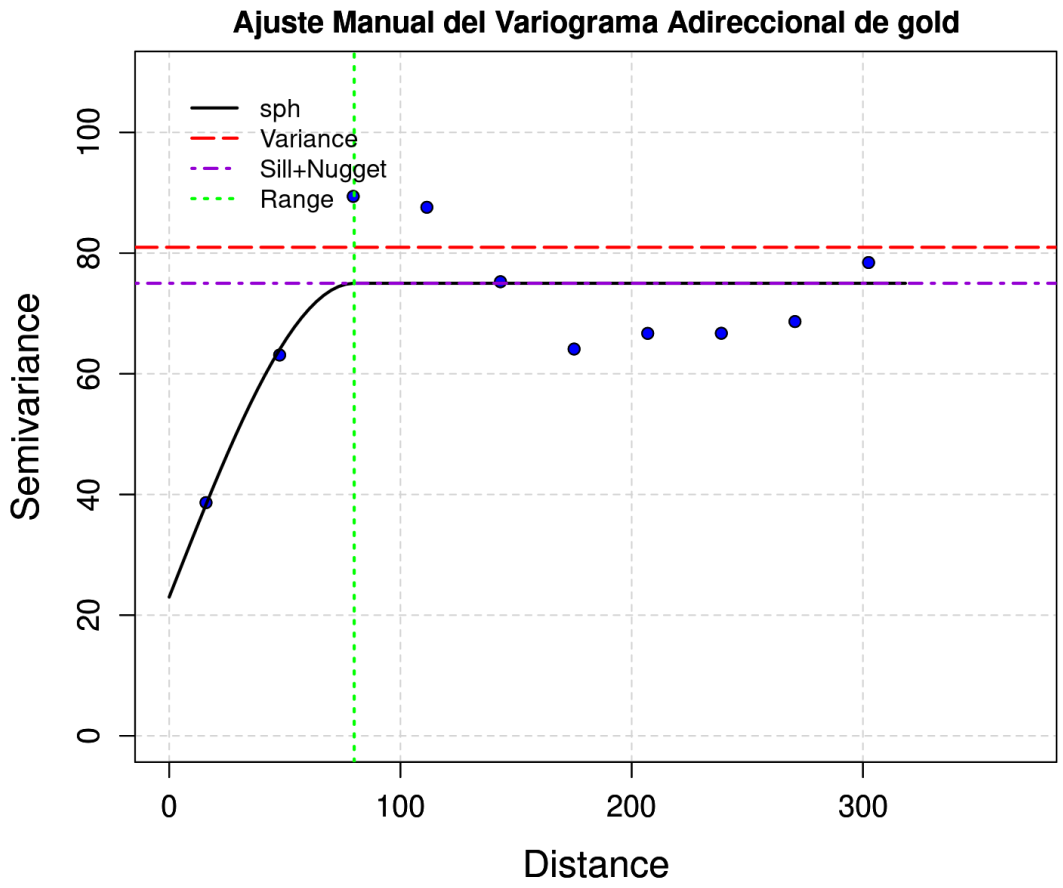


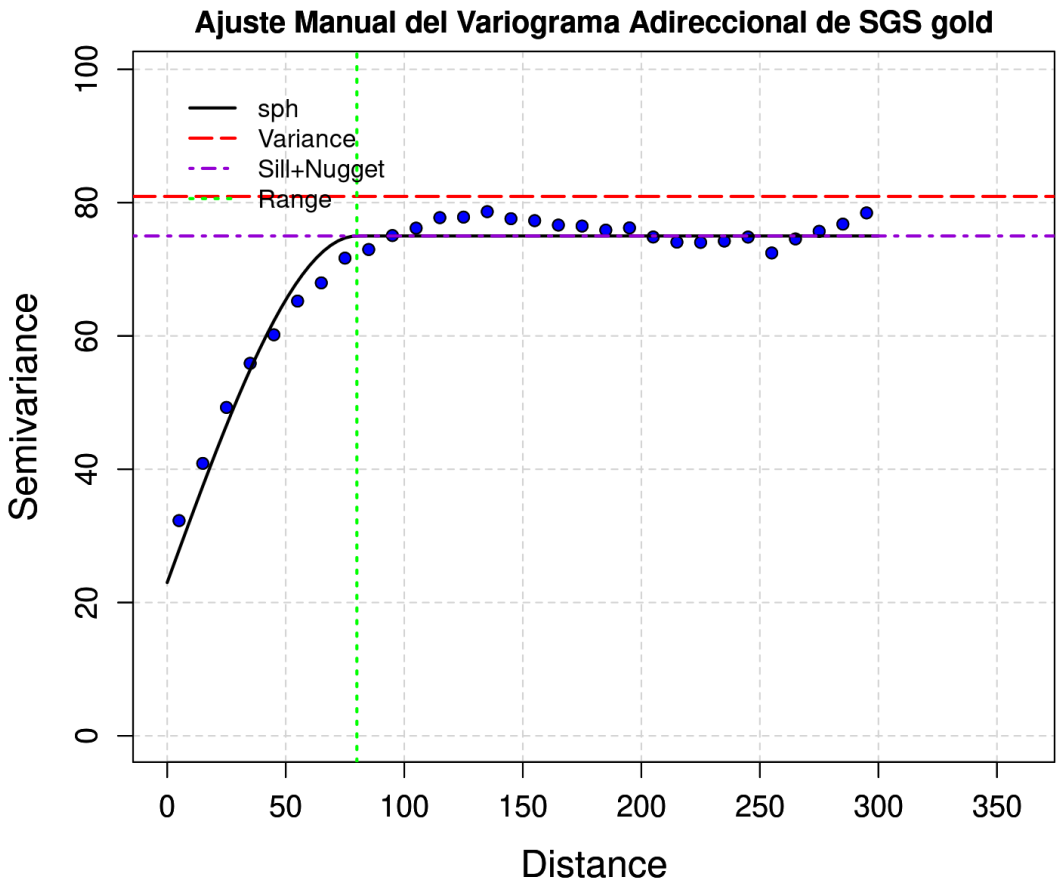




Estadística	Data gold	SGS gold
No_muestras	347	2400
Minimo	0.0001	0.0001
Cuartil_1er	0.1185	0.1064
Mediana	1.1825	1.3541
Media	4.5129	4.8266
Cuartil_3er	4.3893	5.1926
Maximo	60.479	60.479
Rango	60.4789	60.4789
Rango_Intercuartil	4.2708	5.0862
Varianza	80.9684	80.9329
Desv_Estandar	8.9982	8.9963
Simetria	3.578	3.3321
Curtosis	17.7141	15.9993

5.2. Simulación Secuencial Gaussiana





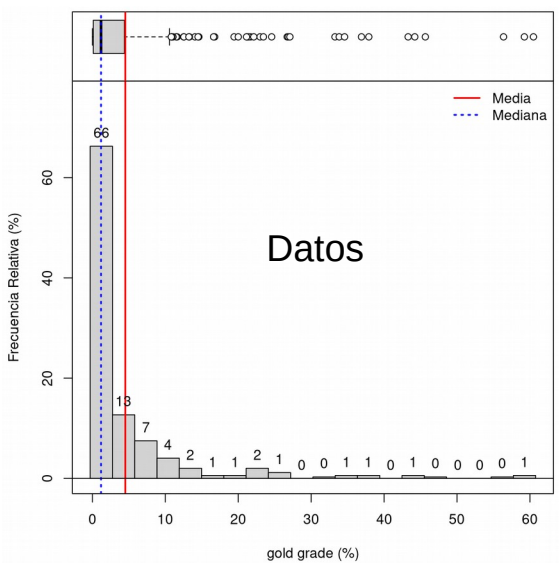
Model	Nugget	Sill+Nugget	Range	MSE
sph	23.0000	75.0000	80.0000	675.3694

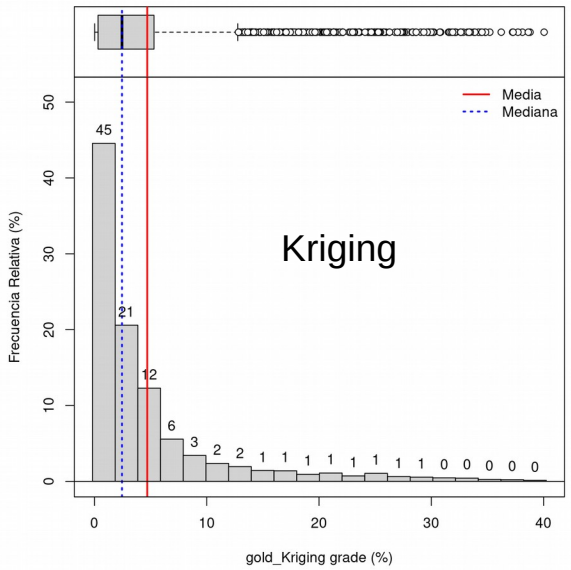
Model	Nugget	Sill+Nugget	Range	MSE
sph	23.0000	75.0000	80.0000	159.6674

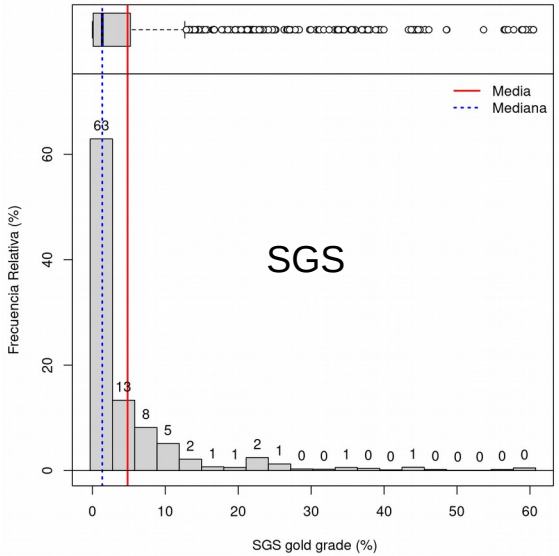
6.Estimación vs. Simulación

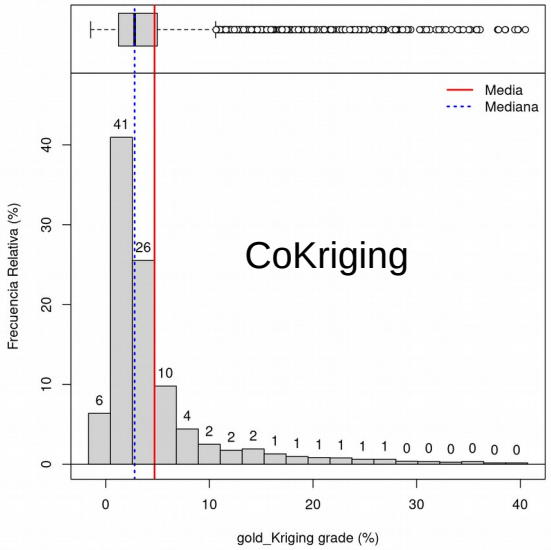
6.Estimación vs. Simulación: Estadística univariada

Oro sin transformar (isotrópico)





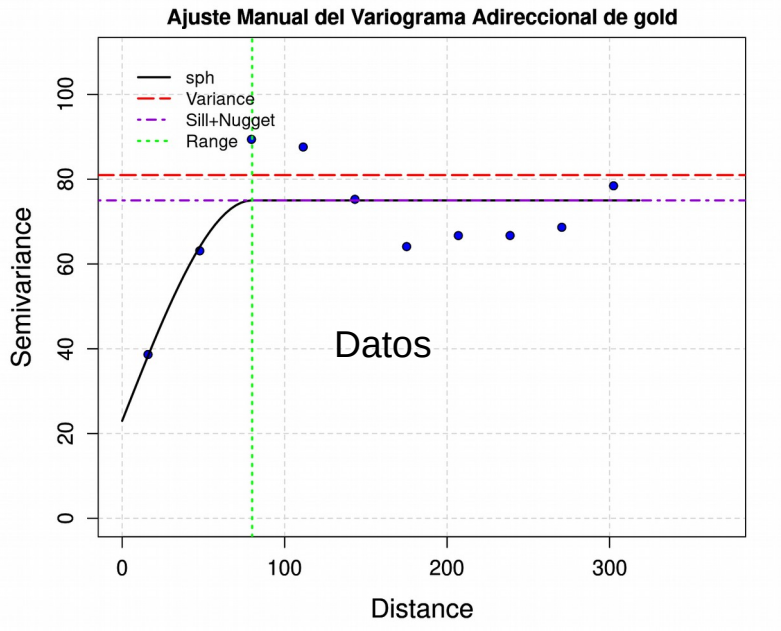




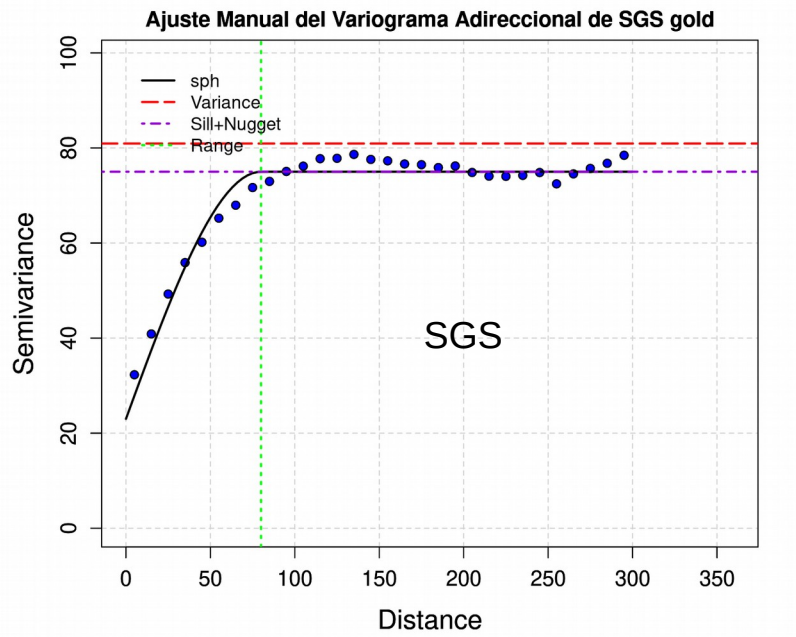
Estadística	Data gold	SGS gold	Kriging gold	CoKriging gold
No_muestras	347	2400	2370	2400
Minimo	0.0001	0.0001	0.0177	-1.4494
Cuartil_1er	0.1185	0.1064	0.3172	1.2293
Mediana	1.1825	1.3541	2.448	2.7884
Media	4.5129	4.8266	4.6957	4.708
Cuartil_3er	4.3893	5.1926	5.3008	4.9795
Maximo	60.479	60.479	40.0454	40.4925
Rango	60.4789	60.4789	40.0278	41.9418
Rango_Intercuartil	4.2708	5.0862	4.9836	3.7502
Varianza	80.9684	80.9329	46.2757	37.7874
Desv_Estandar	8.9982	8.9963	6.8026	6.1471
Simetria	3.578	3.3321	2.4269	2.8147
Curtosis	17.7141	15.9993	9.1155	11.9132

6.Estimación vs. Simulación: Correlación espacial

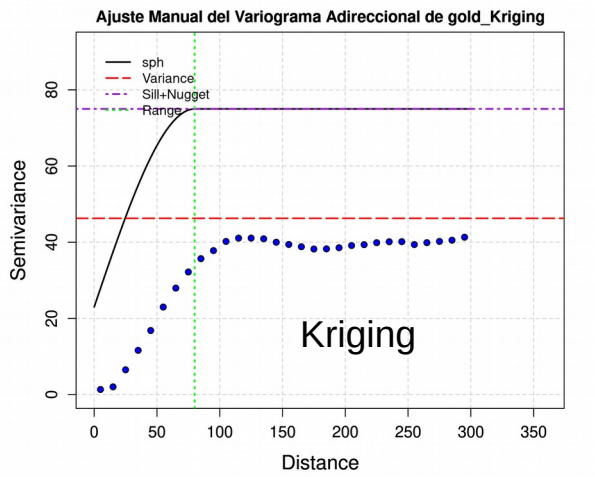
Oro sin transformar (isotrópico)



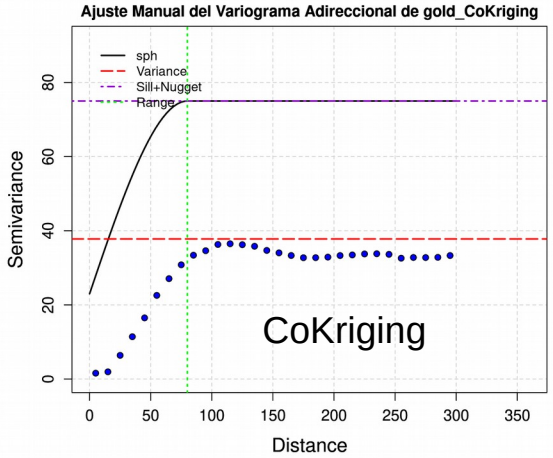
Model	Nugget	Sill+Nugget	Range	MSE
sph	23.0000	75.0000	80.0000	675.3694



Model	Nugget	Sill+Nugget	Range	MSE
sph	23.0000	75.0000	80.0000	159.6674



Model	Nugget	Sill+Nugget	Range	MSE
sph	23.0000	75.0000	80.0000	41040.7040

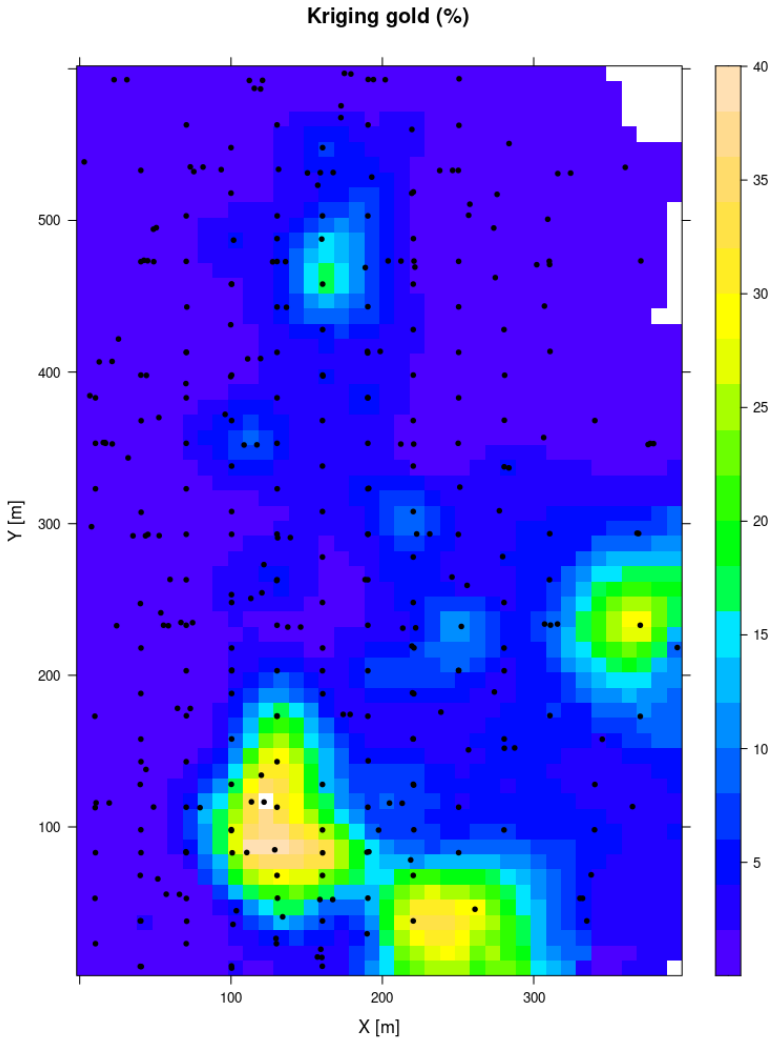


Model	Nugget	Sill+Nugget	Range	MSE
sph	23.0000	75.0000	80.0000	50836.3844

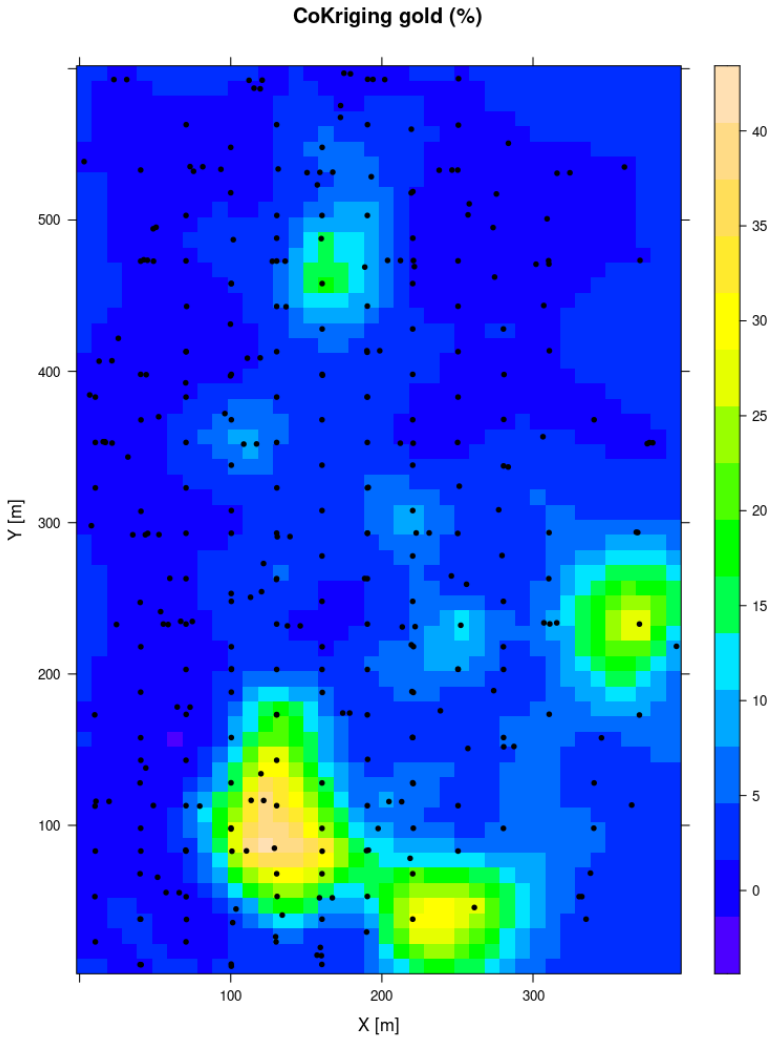
6.Estimación vs. Simulación: Distribución espacial

Oro sin transformar (isotrópico)

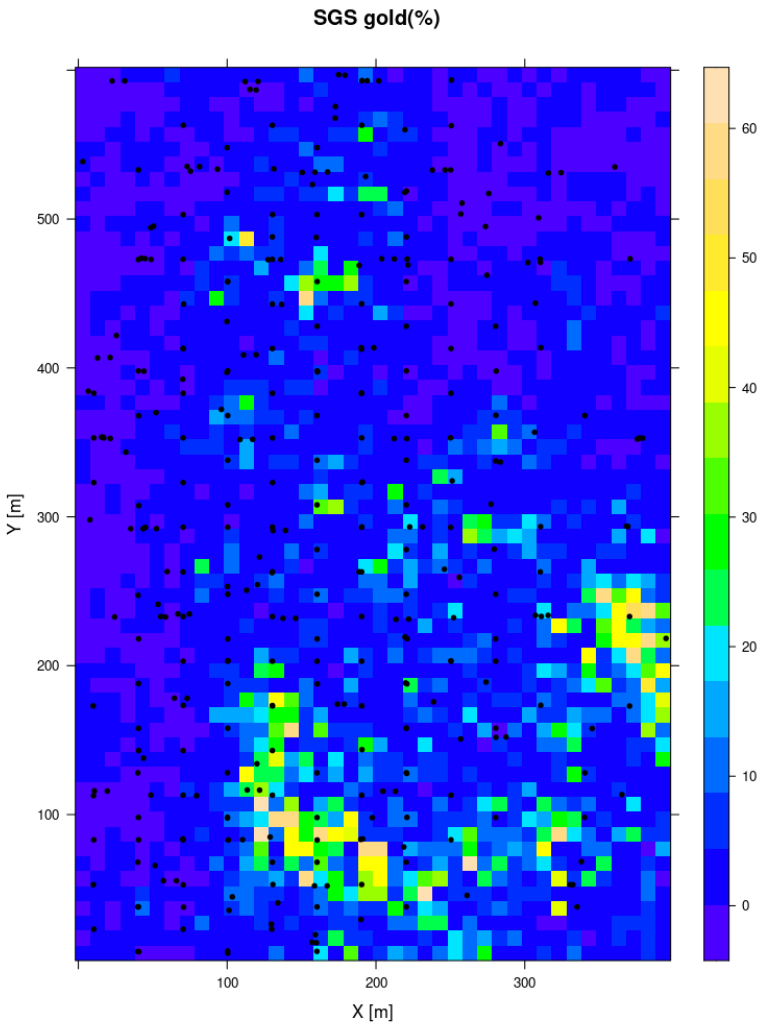
Kriging



CoKriging



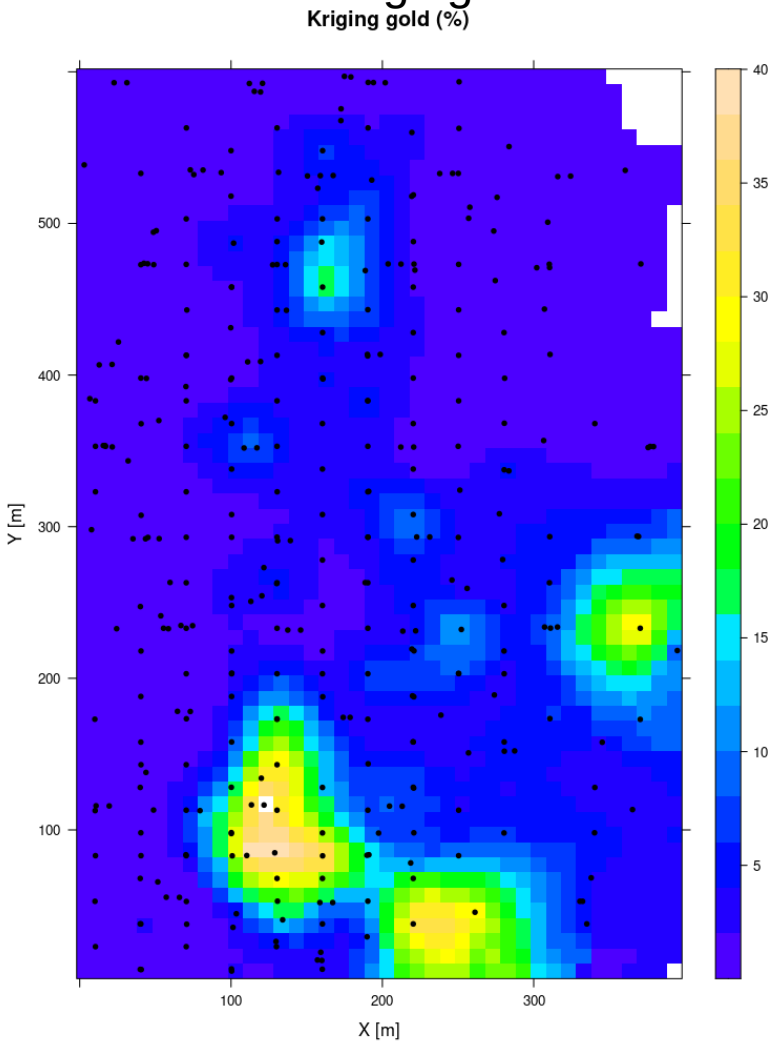
1 simulación SGS



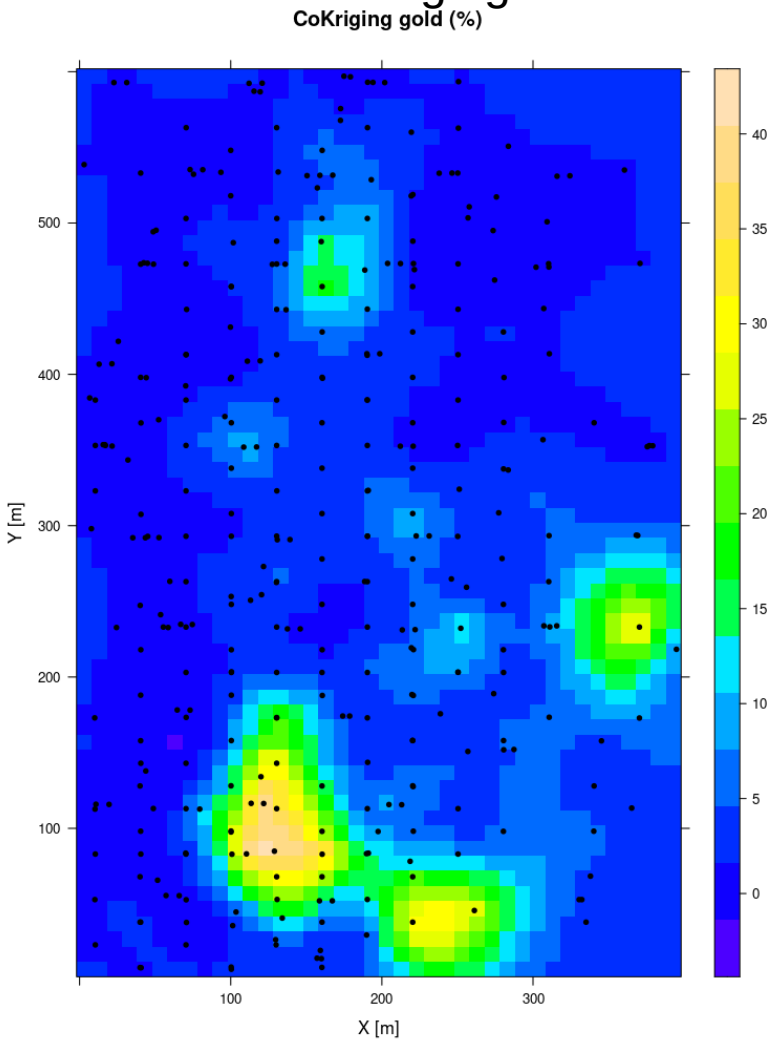
6.Estimación vs. Simulación: Distribución espacial

Oro sin transformar (isotrópico)

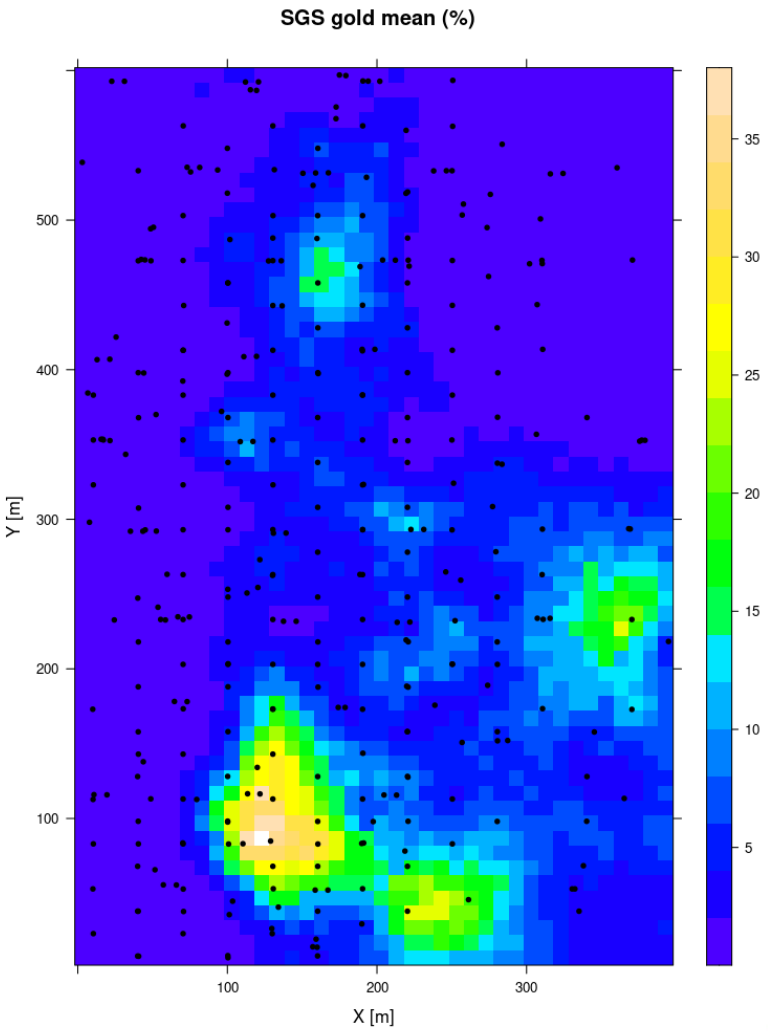
Kriging



CoKriging



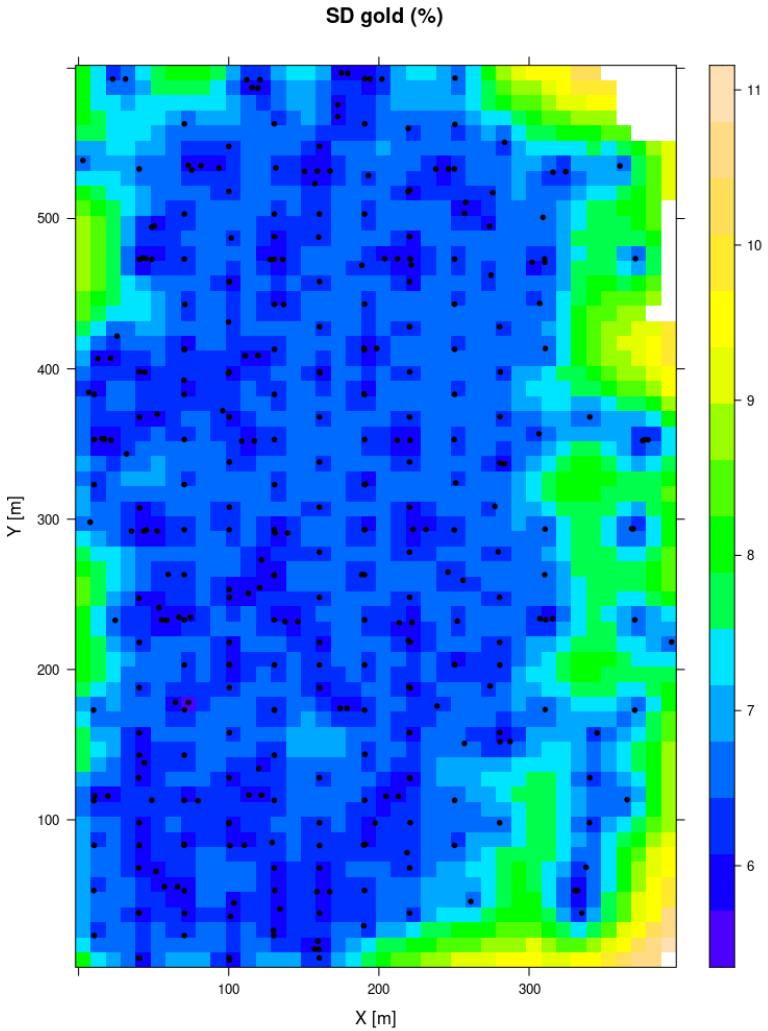
La media de 100 simulaciones SGS



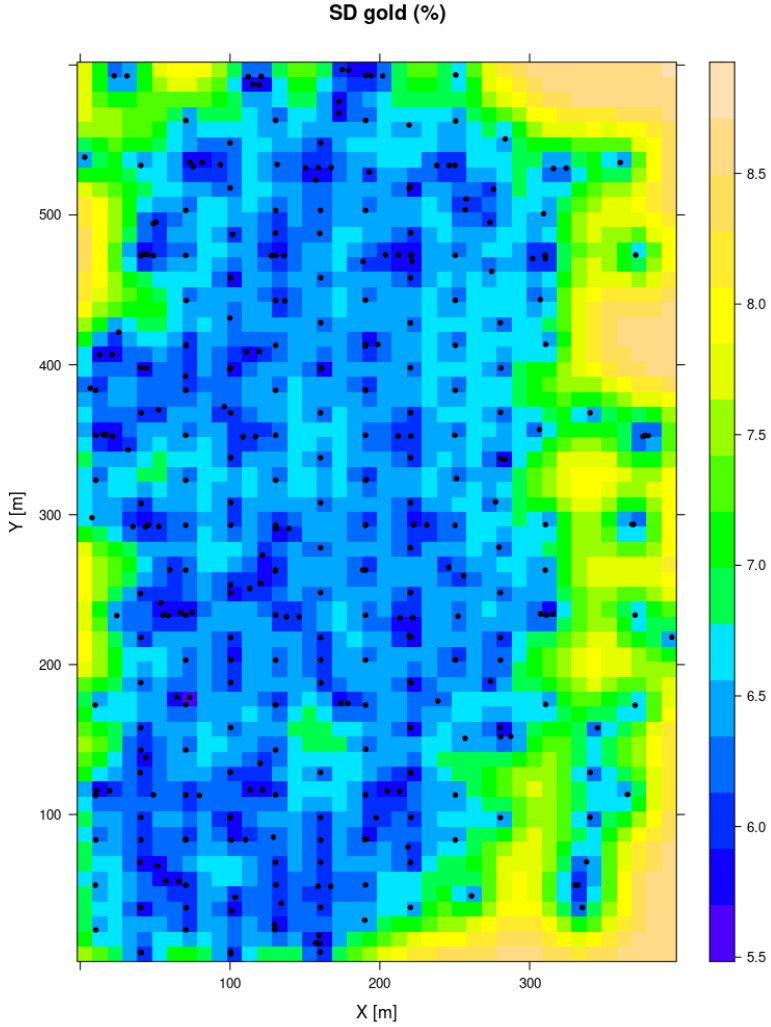
6.Estimación vs. Simulación: Desviación estándar

Oro sin transformar (isotrópico)

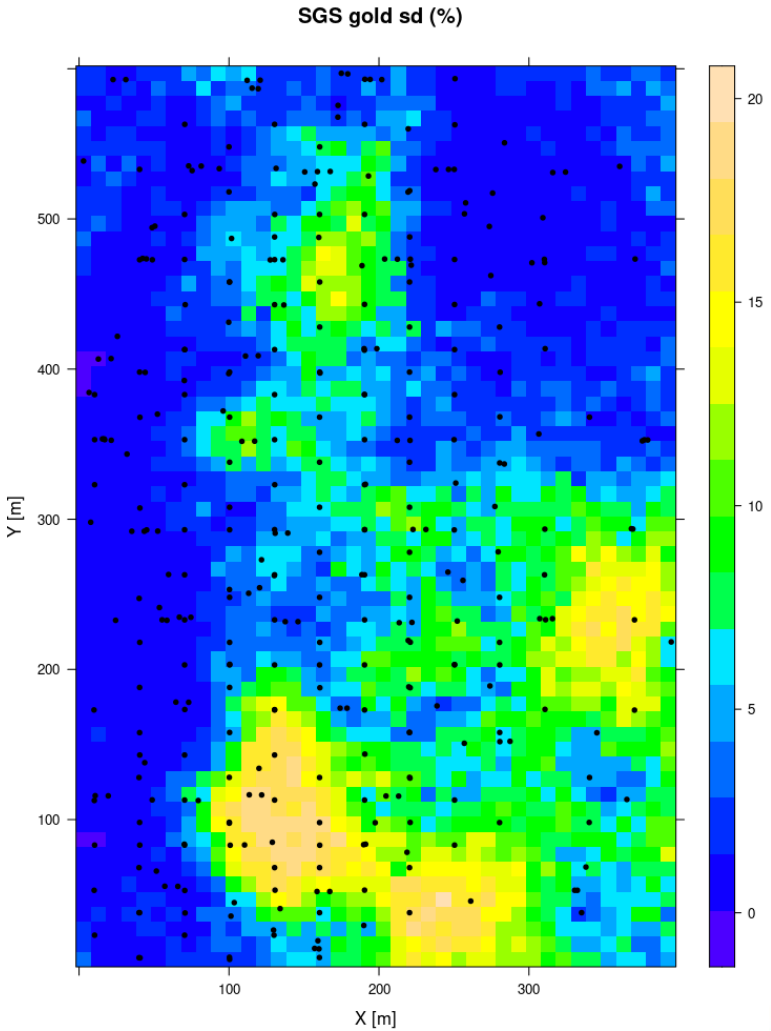
Kriging



CoKriging



SGS



Gracias por su atención