A local geoid model from GNSS and vertical control point using interpolation method in Benton County.

Project By Kasidet Srisutha

CE560 Advanced GIS

Winter 2022

Table of Contents

Introduction

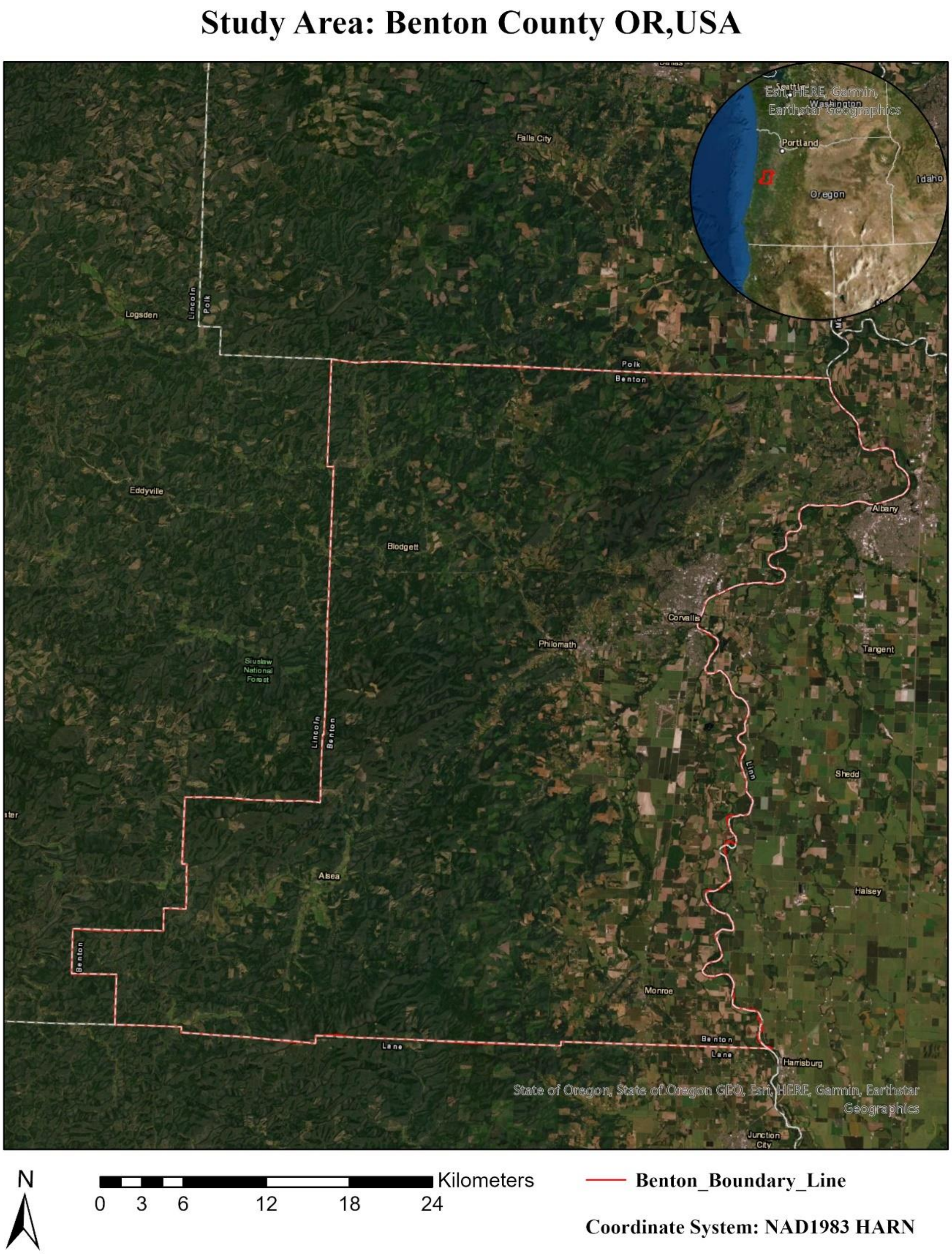
A geoid is the surface that take under influence of the Earth's gravity, all points of the geoid surface have the same geopotential. Generally, the geoid surface can be determined by various methods such as directly measurement by specific instrument or retrieving from publish geoid model. However, there is another one method that can be applied which is determined by GNSS data and common vertical control points.

Firstly, the GNSS data contains horizontal and vertical components, in this project, I focus on the vertical component which is an Ellipsoidal height. Secondly, the common control points provide an Orthometric height. From the relationship in the reference height in Geomatics Engineering, we know that Ellipsoidal height = Orthometric height + Geoid height($h = H + N$). Then, we can calculate the Geoid height from this relationship and it will be used to generate the geoid surface or model for the area of interest.

Objectives

a) To create a local geoid model/surface from GNSS data and common vertical points.
b) To estimate the geoid height within the known values which are Ellipsoidal and Orthometric height.
c) To study different interpolation methods in ArcGIS pro to interpolate the geoid values.
d) To visualize the local geoid model with ArcGIS pro.
e) To find the optimal interpolation method for a study area.
f) To validate the result with published model.

Study area


Study Area: Benton County OR,USA
Falls City
Logsden
Lincoln
Polk
Benton
Eddyville
Blodgett
Albany
Corvallis
Philomath
Tangent
Siuslaw National Forest
Linn
Shedd
Alsea
Halsey
Monroe
Lane
Harrisburg
Junction City
State of Oregon, State of Oregon GEO, Esri, HERE, Garmin, Earthstar Geographics
Esri, HERE, Garmin, Earthstar Geographics
Washington
Portland
Oregon
Idaho
N
Kilometers
0 3 6 12 18 24
Benton_Boundary_Line
Coordinate System: NAD1983 HARN

Datasets

1) Point features
    a. The GNSS data set from National Geodetic Survey(NGS) available from NGS data explorer website. This GNSS data is a set of GNSS coordinates comprise of horizontal and vertical components. For this project, there will be 51 GNSS stations involved.
    b. The set of common vertical control points corresponding to the GNSS coordinates.
    c. Data geometry and format: Point features, Vector.
    d. Data accuracy:
        I. Horizontal components: 1 cm.
        II. Vertical components: 2 cm.
    e. Coordinate system: NAD1983 HARN(High Accuracy Reference Network) meters.
    f. Datum:
        I. Ellipsoid reference datum: NAD83(2011) meters.
        II. Vertical datum: NAVD88 meters.

2) Polygon feature
    a. The Benton County polygon from Benton County GIS departments

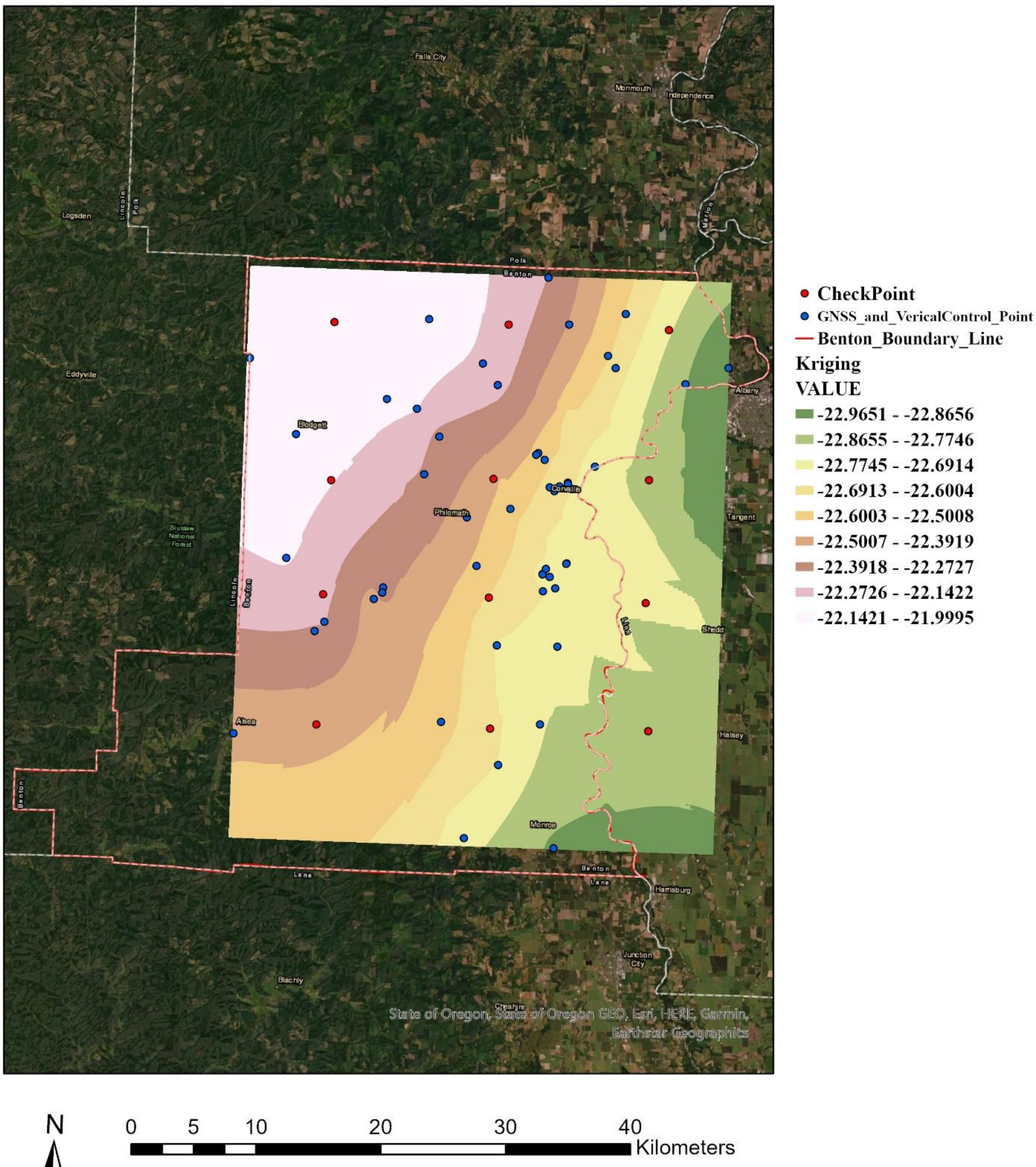
Methodology and GIS steps

1) Import all data sets into ArcGIS pro e.g. the point and polygon features.
2) Select the elevation and ellipsoidal height in the attribute table and copy it into the new layer.
3) Create line or boundary of the Benton County from the Benton County polygon using Polygon to Line Geoprocessing Toolbox.
4) Calculate the Geoid height in the attribute table from h=H+N relationship.
   Then, we can get the Geoid height = Ellipsoidal Height(ELLIP_HT Field) – Orthometric Height(Elevation Field)
5) Apply the interpolation method such as Kriging, IDW(Inverse Distance Weighted), Spline and Trend with linear regression from the Geoprocessing Toolbox to generate(interpolate) the Geoid Height within the boundary.
6) Visualize the geoid surfaces from different interpolation methods into the map.
7) Add check points to the current map to perform the validation with published geoid model from NGS(Geoid 18 model with the same datum reference).
8) Calculate the Root Mean Square Error(RMSE) of the interpolated Geoid Height.
9) Evaluate the minimum RMSE to get the best geoid surface result.

Results

1. Geoid surface using Kriging interpolation.

Geoid surface using Kriging

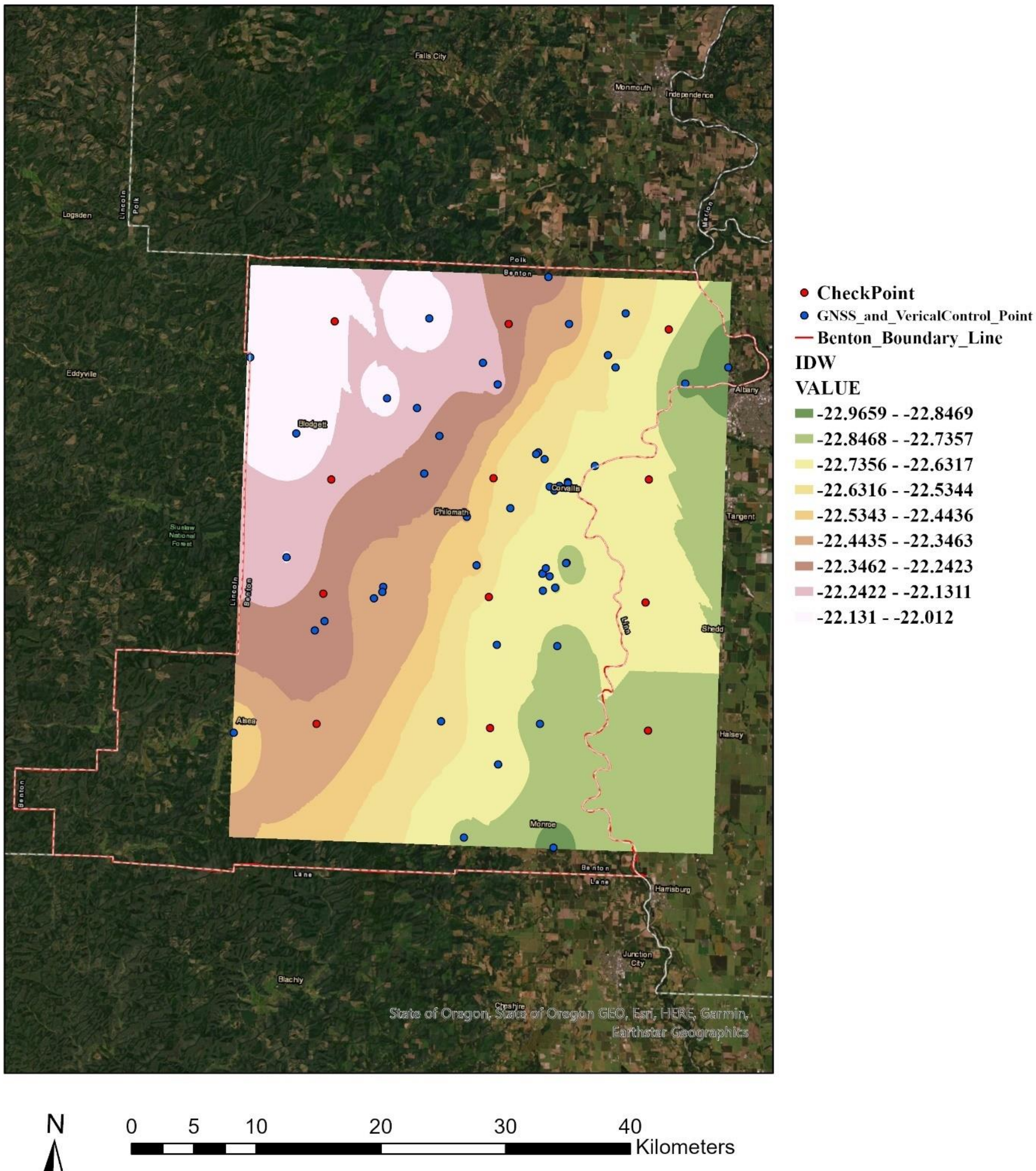


The map depicts the Geoid surface of Benton County using Kriging interpolation.

Coordinate system: NAD1983 HARN, meters.

2. Geoid surface using IDW(Inverse Distance Weighted) interpolation.

Geoid surface using IDW

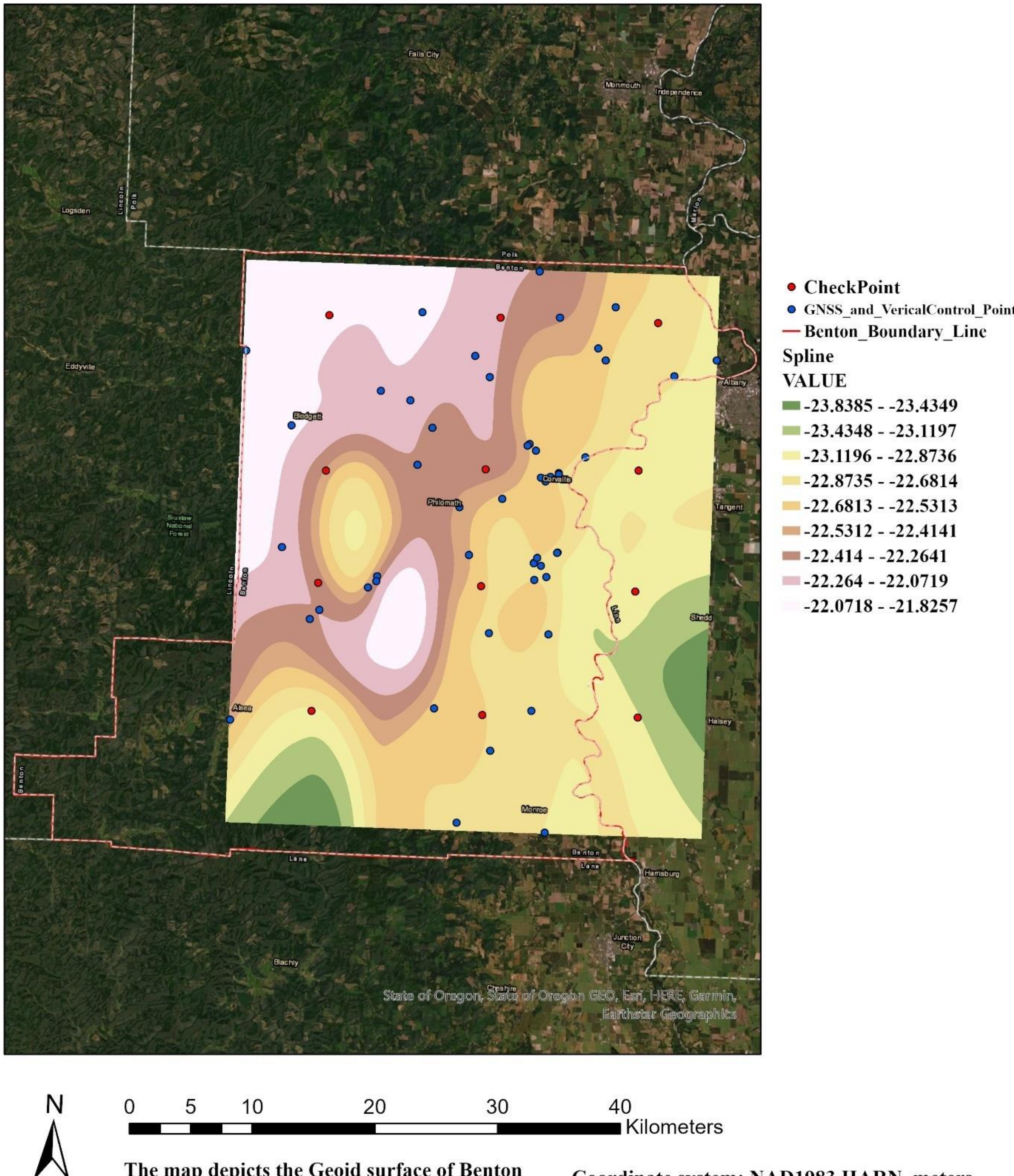


The map depicts the Geoid surface of Benton County using IDW interpolation.

Coordinate system: NAD1983 HARN, meters.

3. Geoid surface using Spline interpolation.

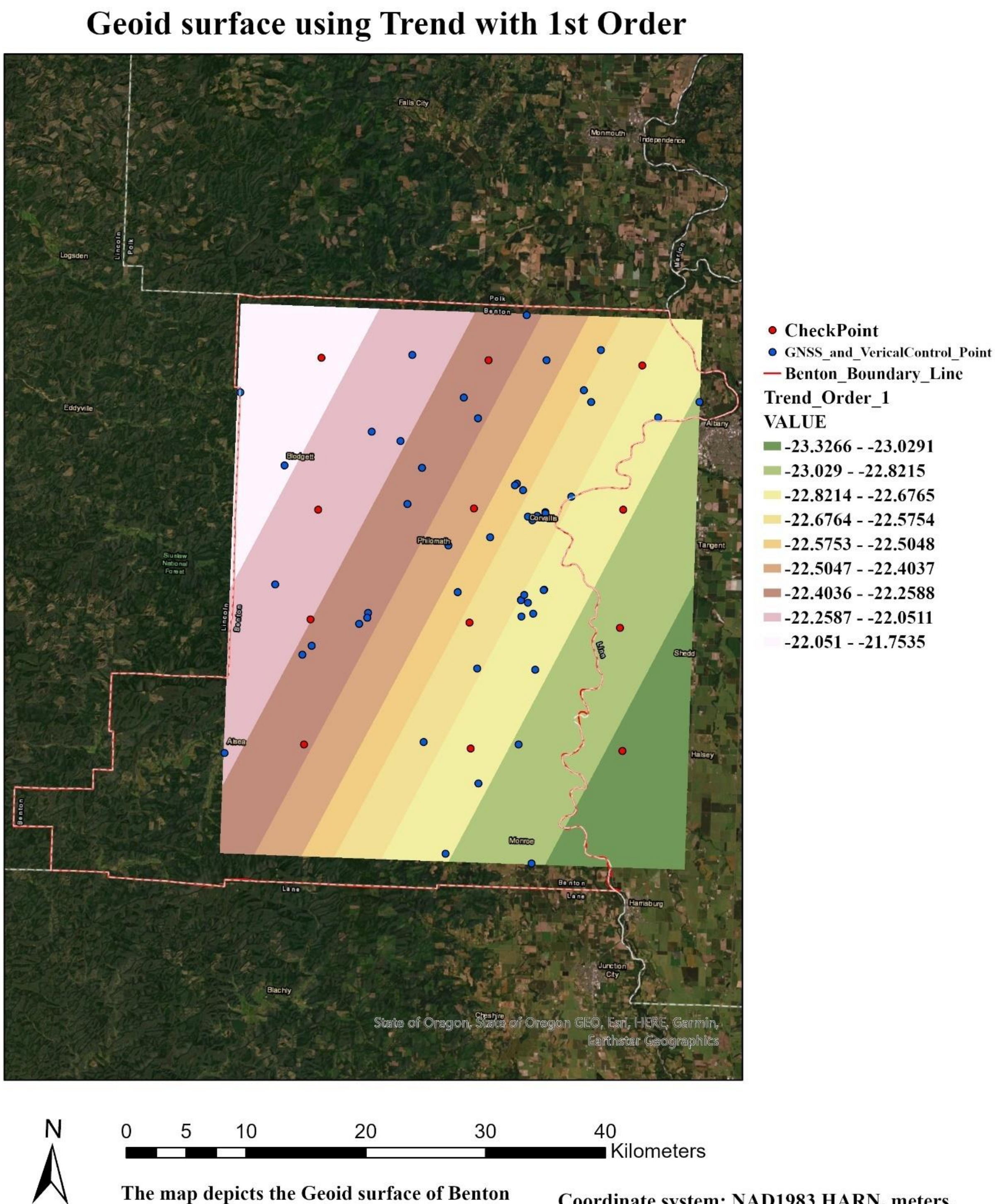
Geoid surface using Spline



The map depicts the Geoid surface of Benton County using Spline interpolation.

Coordinate system: NAD1983 HARN, meters.

4. Geoid surface using Trend interpolation with 1st order polynomial.

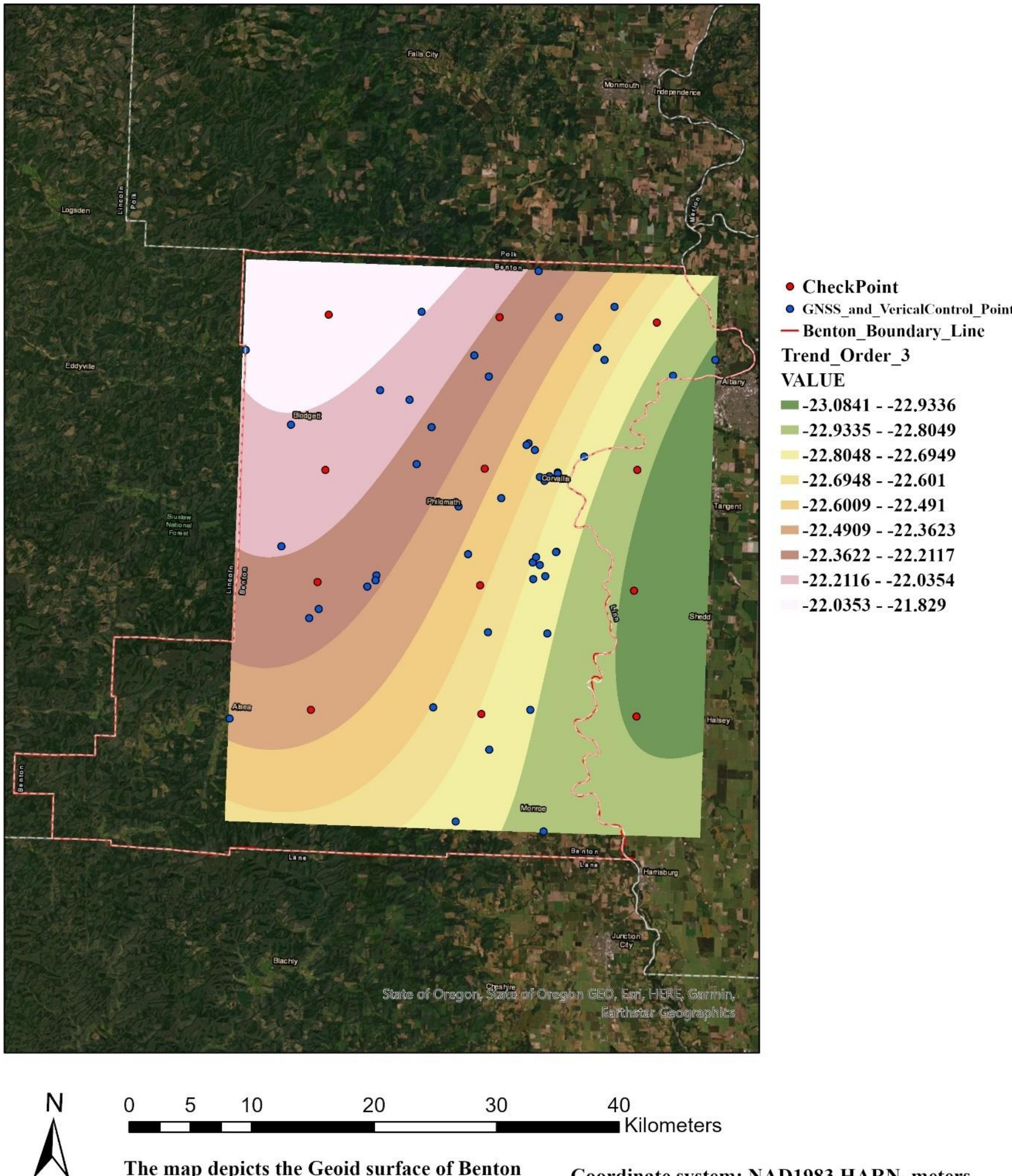


The map depicts the Geoid surface of Benton County using Linear Trend Regression interpolation with 1st order polynomial.

Coordinate system: NAD1983 HARN, meters.

5. Geoid surface using Trend interpolation with 3rd order polynomial.

Geoid surface using Trend with 3rd Order

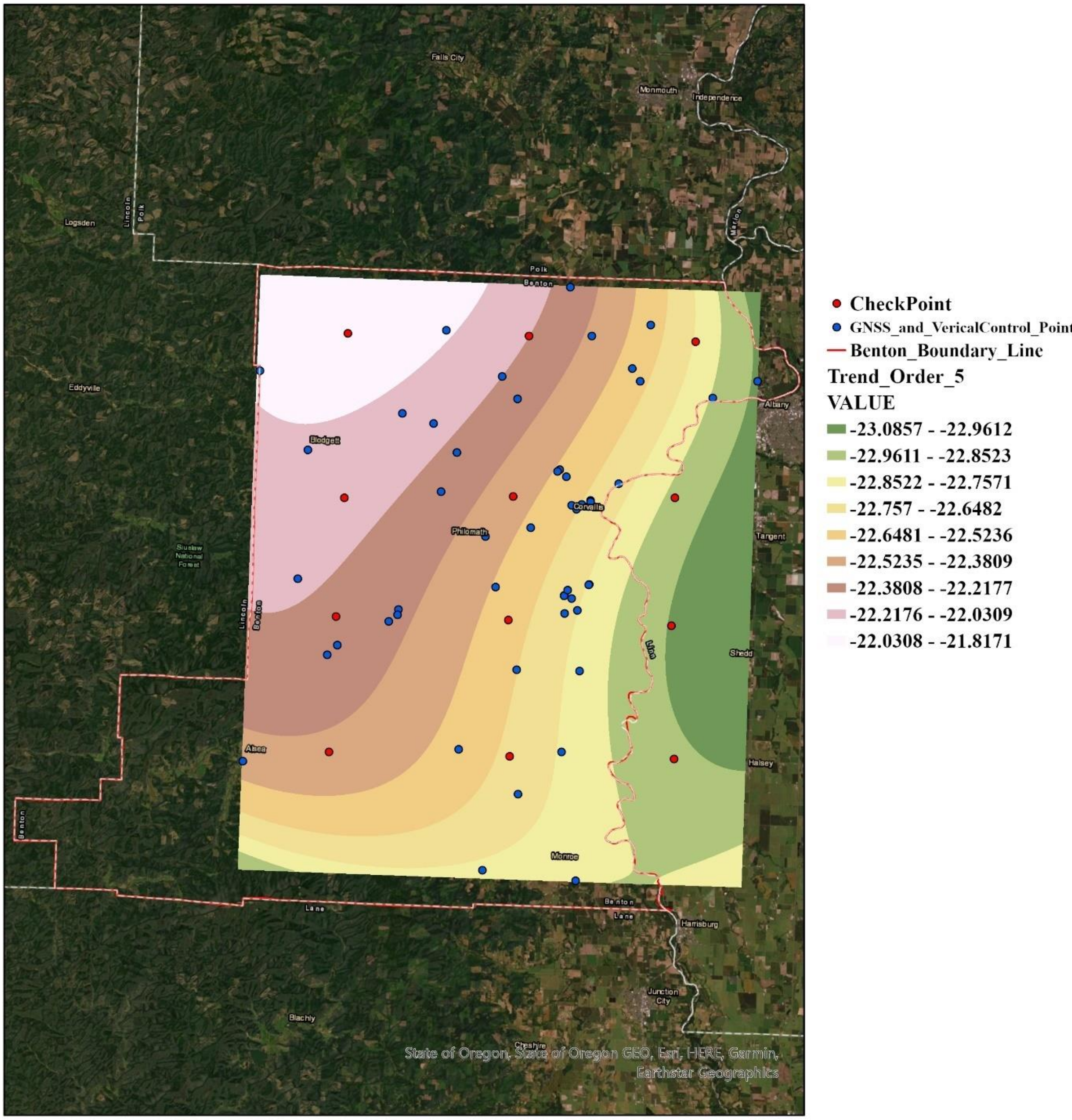


The map depicts the Geoid surface of Benton County using Linear Trend Regression interpolation with 3rd order polynomial.

Coordinate system: NAD1983 HARN, meters.

6. Geoid surface using Trend interpolation with 5th order polynomial.

Geoid surface using Trend with 5th Order



N

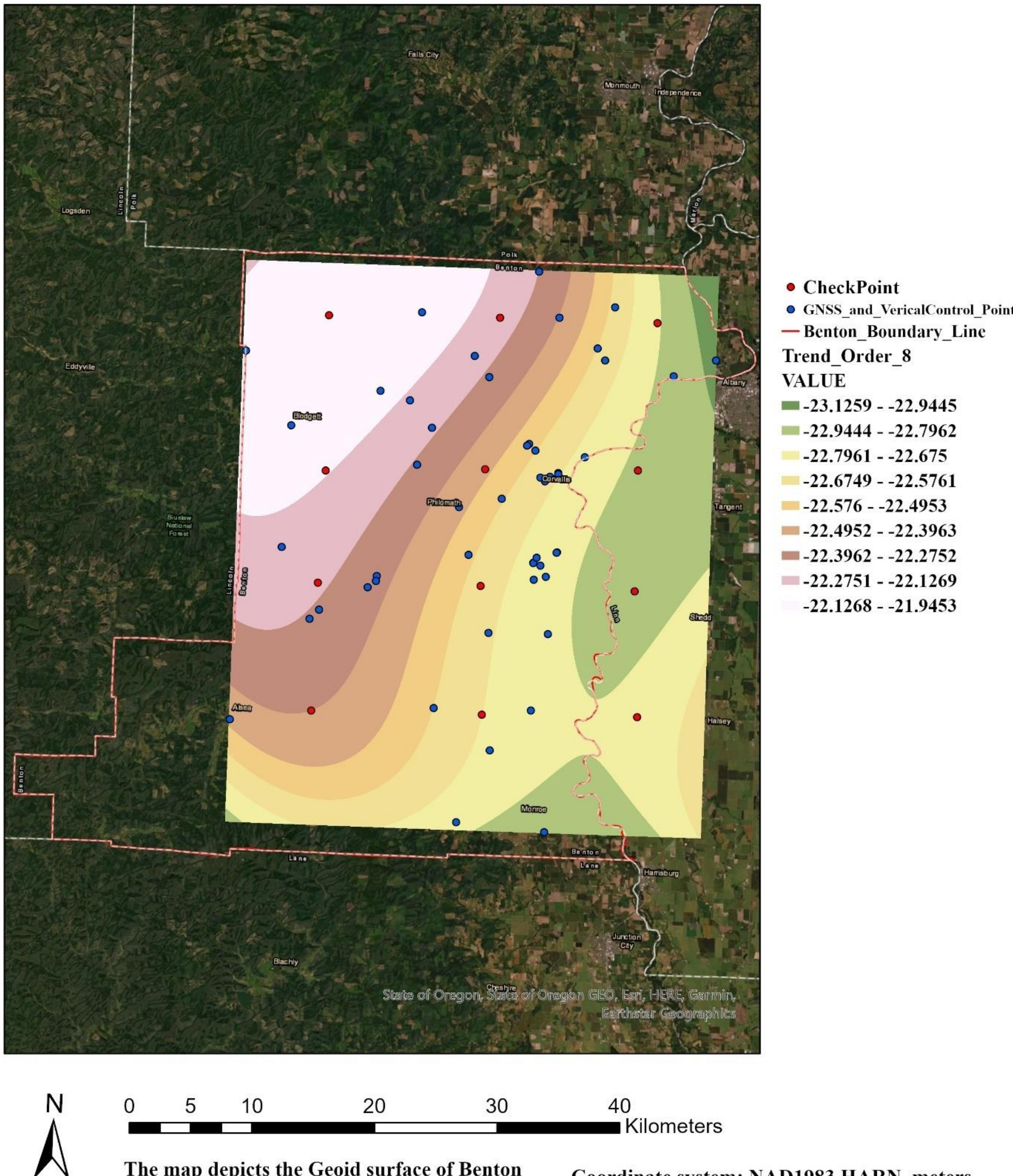
0 5 10 20 30 40 Kilometers

The map depicts the Geoid surface of Benton County using Linear Trend Regression interpolation with 5th order polynomial.

Coordinate system: NAD1983 HARN, meters.

7. Geoid surface using Trend interpolation with 8th order polynomial.

Geoid surface using Trend with 8th Order



The map depicts the Geoid surface of Benton County using Linear Trend Regression interpolation with 8th order polynomial.

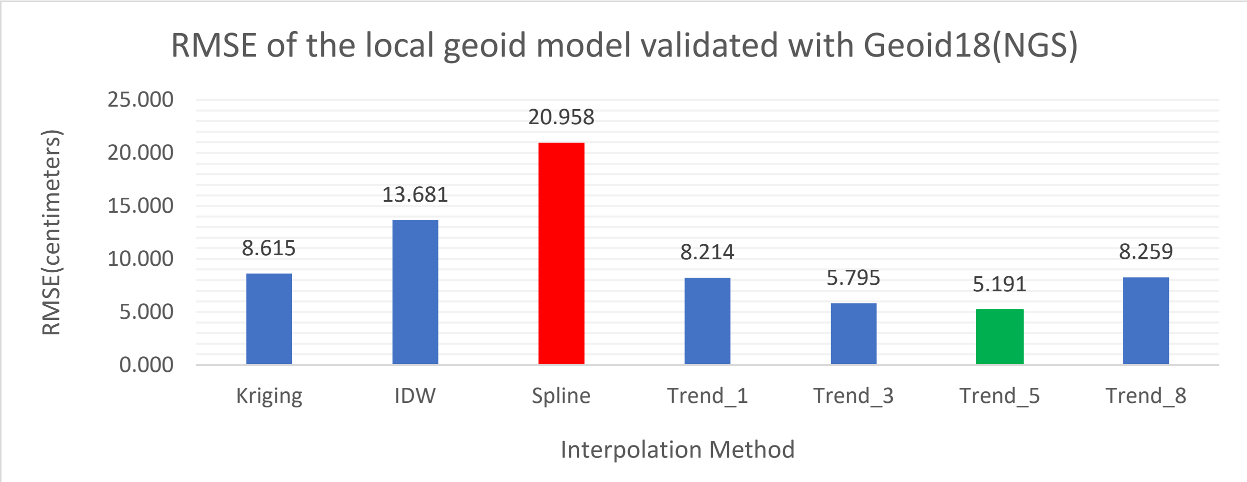
Coordinate system: NAD1983 HARN, meters.

8. Root Mean Square Error

To perform the validation of the interpolated geoid surface with published geoid model from NGS which is geoid18 model. Then, the RMSE of the check points can be determined by the geoid18 model – interpolated geoid surface from ArcGIS.

The RMSE can be calculated following the equation below by using 12 check points as mentioned earlier.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{12}(Geoid18, NGS_i - Interpolated\ Geoid, ArcGIS_i)^2}{12}}$$



Conclusion

From the all Geoid surface results, the RMSE were calculated and the highest RMSE is 20.958 cm from Spline method and the lowest RMSE is 5.191 cm from Linear Regression Trend with 5^{th} order polynomial method. Then, I can confirm that the optimal interpolation method for Benton County area is Linear Regression Trend with 5^{th} order polynomial, although the order of polynomial is increased, it does not decrease the RMSE as we can see that the RMSE of 8^{th} order is still high.

The RMSE of the Linear Regression Trend with 5^{th} order polynomial is about 5 cm which is acceptable for certain work. Therefore, the minimum requirement of the vertical accuracy is essential. However, we cannot assume to apply this Trend 5^{th} order interpolation method for any other areas because each area has specific characteristics of the elevation.

To increase the accuracy, we could try to increase the common points of GNSS and vertical control points and to distribute the common points uniformly over the interpolated area. One of the disadvantage of the interpolation method is that we cannot interpolate or estimate the values outside the known values, if we want to do so we might to try extrapolation but I think it is not common in the GIS to perform extrapolation.

References

[1] Heeto Abdulrahman. (2021). Determination of the local geoid model in Duhok Region, University of Duhok Campus as a Case study. Ain Shams Engineering Journal, 12(2), 1293–1304. https://doi.org/10.1016/j.asej.2020.10.004

[2] Ismail, Din, A. H. M., Uti, M. N., & Omar, A. H. (2018). ESTABLISHMENT OF NEW FITTED GEOID MODEL IN UNIVERSITI TEKNOLOGI MALAYSIA. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences., XLII-4/W9, 27–33. https://doi.org/10.5194/isprs-archives-XLII-4-W9-27-2018

[3] Al-Krargy, E. M., Doma, M. I., & Dawod, G. M. (2014). Towards an accurate definition of the local geoid model in Egypt using GPS/leveling data: a case study at Rosetta zone. International Journal of Innovative Science and Modern Engineering (IJISME), 2(11).

[4] US Department of Commerce, N. O. A. A. (n.d.). National Spatial Reference System, geodetic control map. Home. Retrieved January 23, 2022, from https://geodesy.noaa.gov/NGSDataExplorer

[4] US Department of Commerce, N. O. A. A. (n.d.). Computation of GEOID18 Geoid Height. Retrieved March 1, 2022, from https://geodesy.noaa.gov/GEOID/GEOID18/computation.html

[5] Benton County GIS. Benton County Website. Retrieved March 1, 2022, from https://gis.co.benton.or.us/gisdata/Boundaries

Appendix A

The full calculated RMSE table and check points coordinates.

CP#	Lat(N)			Lon(W)			Geoid18	Kriging	Diff	IDW	Diff	Spline	Diff	Trend_1	Diff	Trend_3	Diff	Trend_5	Diff	Trend_8	Diff
1	44	40	32.46767	123	30	45.27734	-21.919	-22.013	0.094	-22.125	0.206	-22.046	0.127	-21.982	0.063	-21.910	-0.009	-21.900	-0.019	-21.947	0.028
2	44	40	42.83367	123	20	12.52694	-22.159	-22.206	0.047	-22.286	0.127	-22.236	0.077	-22.339	0.180	-22.230	0.071	-22.214	0.055	-22.210	0.051
3	44	40	42.06633	123	10	29.56968	-22.761	-22.763	0.002	-22.700	-0.061	-22.757	-0.004	-22.674	-0.087	-22.737	-0.024	-22.765	0.004	-22.782	0.021
4	44	33	42.73414	123	30	36.45405	-22.097	-22.134	0.037	-22.186	0.089	-22.428	0.331	-22.148	0.051	-22.127	0.030	-22.147	0.050	-22.117	0.020
5	44	34	1.00187	123	20	47.19601	-22.474	-22.459	-0.015	-22.517	0.043	-22.350	-0.124	-22.479	0.005	-22.456	-0.018	-22.464	-0.010	-22.477	0.003
6	44	34	11.84208	123	11	22.64538	-22.864	-22.805	-0.059	-22.702	-0.162	-22.913	0.049	-22.795	-0.069	-22.898	0.034	-22.878	0.014	-22.822	-0.042
7	44	28	46.1109	123	30	50.26857	-22.139	-22.245	0.106	-22.283	0.144	-22.349	0.210	-22.257	0.118	-22.268	0.129	-22.261	0.122	-22.256	0.117
8	44	28	52.76135	123	20	48.73876	-22.609	-22.604	-0.005	-22.632	0.023	-22.639	0.030	-22.596	-0.013	-22.583	-0.026	-22.593	-0.016	-22.616	0.007
9	44	28	51.74888	123	11	20.29311	-22.938	-22.773	-0.165	-22.726	-0.212	-22.995	0.057	-22.920	-0.018	-22.959	0.021	-22.968	0.030	-22.835	-0.103
10	44	23	7.76353	123	30	57.69648	-22.335	-22.450	0.115	-22.384	0.049	-22.899	0.564	-22.381	0.046	-22.439	0.104	-22.420	0.085	-22.394	0.059
11	44	23	12.17417	123	20	27.82296	-22.658	-22.671	0.013	-22.695	0.037	-22.673	0.015	-22.743	0.085	-22.704	0.046	-22.674	0.016	-22.675	0.017
12	44	23	20.19855	123	10	56.55319	-22.986	-22.841	-0.145	-22.749	-0.237	-23.094	0.108	-23.063	0.077	-22.948	-0.038	-22.933	-0.053	-22.768	-0.218
								RMSE (m.)	0.086		0.137		0.210		0.082		0.058		0.052		0.083
								RMSE (cm.)	8.615		13.681		20.958		8.214		5.795		5.191		8.259
									Kriging		IDW		Spline		Trend_1		Trend_3		Trend_5		Trend_8
													Worst						Best		