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AN ASSESSMENT OF THE IMPACT OF DEM INTERPOLATION TECHNIQUE, RESOLUTION, AND TERRAIN TYPE ON THE EXTRACTION OF DRAINAGE NETWORK

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ABSTRACT

This research used points extracted from high-resolution DEMs (1m) to investigate the impact of resolution, interpolation method and topography on the accuracy of drainage network extraction. The investigation was conducted by evaluating the accuracy of the estimations of streams length, streams number, drainage density, and the Longitudinal Root Mean Square Error (LRMSE) of the extracted drainage networks from different DEMs interpolated using Topo to raster, Natural Neighbor (NN), kriging and IDW interpolation methods at 5, 10, 15 and 20m resolutions over moderate, steep, and gentle slope terrain. Each evaluation conducted yielded a different result, but the accuracy of the streams length estimation for most of the DEMs at all the sites increases with an increase in streams order. The total lengths of all the streams of each of the extracted networks at gentle and steep slope sites are shorter than those of the corresponding reference networks though, 15 and 20m kriging and IDW DEMs created longer streams at the moderate slope site. IDW DEMs have proven reliable for streams length estimation while Topo to raster 5, 10, and 15m for streams number estimation. In general, N.N. extracted networks are the only networks that show consistency in the streams length and number estimations, drainage density estimation as well as in LRMSE and DEM RMSE computation at all the resolutions and for all the sites. Therefore, the accuracy of N.N. DEMs and their derivatives do not rapidly change with change in resolution, especially between 5 and 20m at all (steep, gentle and moderate) terrain types.

KEYWORDS: DEM, Drainage Network, Drainage Density, Interpolation method, LRMSE

1.1 INTRODUCTION

Digital Elevation Model (DEM) comes from the generic concept of digital terrain analysis, which defines the relief features and elevation of terrain in a digital format commonly known as Digital Terrain Model (DTM) and Digital Surface Model (DSM) (Zaidi et al., 2018). It is considered an array representation of squared cells (pixels) with an elevation value associated with each pixel. The elevation values can be obtained from contour lines, topographic maps, field surveys, photogrammetry techniques, radar interferometry, and laser altimetry. DEM is the generally adopted data structure for storing topographic information which can be used in different fields, including hydrological modelling (e.g. Yang et al., 2014), geomorphological and digital soil mapping (e.g. Lin et al., 2013, Nussbaum et al., 2014, Baltensweiler et al., 2017), natural hazard assessment (e.g. Arnone et al., 2016), or ecological species distribution models (e.g. Camathias et al., 2013).

Historically, the data sources and processing techniques for DEMs generation have been evolving rapidly over the last 2 to 3 decades — "from ground surveying and topographic map conversion to passive methods of remote sensing and more recently to active sensing with LiDAR and RADAR" as well as using interferometry. Also, many ready-to-used DEMs are available at different resolutions and at different accuracy levels. Several studies have examined some of the powerful techniques of the data collection (Baltensweiler et al., 2017, Debella-Gilo, 2016) and the accuracies of some of the existing DEMs (Thomas et al., 2015, and Jarihani et al., 2015). However, all these data/methods of data collection have their own strengths as well as weakness, and their selection highly depends on the required accuracy, nature of the terrain, and data availability. However, one of the highly reliable existing global DEMs has been shown to be the hydrologically corrected SRTM (Jarihani et al., 2015).
Elevation data collected using different methods can be

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interpolated using different algorithms to generate DEM. These algorithms are based on the principles of spatial autocorrelation, which assumes that closer points are more similar compared to farther ones. Different interpolation algorithms are available and can be broadly classified into Global/Local Interpolations or Exact/Approximate Interpolations. Global Interpolation algorithms apply a single mathematical function to all observed data points and generally produce smooth surfaces with a change in one input value affecting the entire output (e.g. global polynomial interpolation functions, while the local algorithms apply functions only to small subsets of the data points to create small surfaces that can be linked together to create a composite surface covering the entire study area (e.g. Inverse Distance Weighting (IDW), local polynomial, Nearest Neighbor (NN), and Radial Basis Functions (RBFs)). Exact algorithms produce surfaces that pass precisely through the observed data points without smoothing or altering their values (proximal interpolators, B-splines and Kriging methods). In contrast, the approximate ones do not necessarily honour the observed points but can smooth or alter them to fit a general trend.

In hydrology, the quality and reliability of hydrological applications are highly dependent on the implication of the appropriate spatial data input derived from DEM (Vaze et al., 2010) as well as the scale factor. When the spatial resolution of a DEM is coarsened, the derivatives such as slope, aspect, curvature and drainage patterns may subsequently vary in different ways.

Topographic accuracy, methods of preparation and grid size are all critical for hydrodynamic models to efficiently replicate flow processes (Jarihani et al., 2015). Also, the determination of optimal DEM resolution for hydrological modelling depends on the hydrological process being modelled and the scale of the topographic features controlling it (Roelens et al., 2018). Suppose a DEM is too coarse to represent the topographic features due to surface generalizations. In that case, it will produce narrower slope distributions and lower mean slope gradients with lower gradients on steeper slopes and higher gradients on shallower slopes (Thompson et al., 2001), which can lead to the erroneous predictions of any topographic index (Hancock, 2005; Vaze et al., 2010).

The extraction of drainage networks in flat areas can yield abysmal results due to the weak topographic gradient leading to low accuracy. The flow direction can be determined. However, a very high DEM resolution may be inappropriate, especially for groundwater flow directions modelling, due to its dependence on the general topography of the landscape rather than small-scale surface variations. Therefore, the optimal DEM resolution achieves a balance between appropriate levels of topographic accuracy, data processing and storage requirements, and the need for interpretable outputs (MacMillan et al., 2003; Hengl, 2006; and Liu, 2008).

Several studies have contributed to the evaluation of the properties and characteristics of DEM of various sources and resolutions. Yang et al. (2014) investigated the limitations of using some existing DEMs (e.g. ASTER GDEM) in the extraction of information related to DEM derivatives for hydrological and other applications. Similarly, the effect of DEM accuracy and resolution in hydraulic and hydrologic modelling were studied by Vaze et al. (2010) and Jarihani et al. (2015).

It has been known that different interpolation methods applied over the same data sources may result in different DEMs in different landscapes and at different resolutions (Arun, 2013, Ajvazi and Czimber 2019, and Thomas et al. 2017) for different applications, making it difficult to know which to use for a particular terrain at a given resolution. To the knowledge of this work, there is no particular literature that provides a complex combination of the best interpolation algorithms to be used for a particular landscape to the desired scale/resolution for drainage network extraction using heights point of a degree of importance extracted from high resolution existing DEM. Therefore, this work is designed to address most, if not all, the problems highlighted above, so that at some selected scale or resolution, a spatial analyst can simply identify the best interpolation method to use.

The focus of this paper is to investigate the combined impact of resolution, topography, and interpolation technique on the accuracy of drainage network extraction to determine the best possible combination of DEM interpolation technique, DEM resolution, and terrain type for drainage network extraction.

2.1 METHODOLOGY

This study is basically an assessment of the impact of DEM resolution and interpolation techniques on the accuracy of the extracted drainage network concerning the different nature of the terrain and based on the heights data extracted from existing high-resolution DEMs of the study areas. Therefore, Raster to TIN conversion was used on each of the DEMs to generate TIN, and the TIN's nodes were extracted as the spots height. The vertices of the drainage network extracted from the original DEMs were used together with the TIN's nodes in the extractions of the surfaces 'significant points' according to their degree of importance to the scale of application, as suggested by (Abramov and McEwan, 2004). This is to prevent data redundancy, reduce data source error to the barest minimum, and allow objective selection of spot heights.

The review of the previous work has identified different interpolation algorithms performing differently depending on the scenario; therefore, ANUDEM, kriging, IDW, and N.N. were selected and evaluated in this work due to their reported outstanding performances in terrain interpolation (Debella-Gilo, 2016; Ajvazi and Czimber, 2019; and Abramov and McEwan, 2004). Most of the reviewed work has shown that finer DTM might not necessarily mean better DEM, and some DEM resolutions can provide good results for any type of terrain (Kienzle, 2004), therefore, 5, 10, 15 and 20m interpolation resolution were investigated in this work. Also, each flow-routing algorithm offers a unique method of calculating flow direction and upslope contributing area (Wilson et al., 2008), resulting in different terrain attributes in different landscapes and sometimes different parts of the same landscapes. However, D8 is the widely used flow routing algorithm (Hosseinzadeh 2011); hence, it is selected for this assessment.

2.2 Study sites

The three study sites selected for this study are the Reynolds Creek Experimental Watershed (RCEW), located in Idaho US; Cedar River Municipal Watershed

(CRMW), located in the Cascade Mountains in King County of western Washington State; and the South Fork Eel River watershed (SFERW) located in the northern Mendocino and southern Humboldt counties in northern California. These watersheds were chosen as the result of: the availability of extensive high resolution (1m) airborne LiDAR derived DEM datasets; and also the areas have distinct topographical (and hence hydrographical) characteristics which represent different terrain type and watershed.

2.3 Data used: The data for each of the study sites was collected separately for different projects by different organizations. A brief description of each of the data is given below.

Table 1: Data used

Description	RCWS	CRMW	SHOW
Acquisition Date	October (2015)	August – Sep. (2012)	June (2004)
Dataset Name	Reynolds Creek Critical Zone Observatory 2015 Post-Soda Fire Lidar	Cedar River Municipal Watershed Snow Modeling	South Fork Eel River, CA Watershed Morphology
Elevation Accuracy	5 - 15 cm	5 - 35 cm	5 -10cm
Horizontal Accuracy	1/5,500 x altitude (m AGL); 1 sigma	1/5,500 x altitude (m AGL); 1 sigma	10cm
Area (km^2)	248	70	236
Original Lidar point density (points/m^2)	16.95	7.2	2.64
Extent (latitude)	43.16°N - 43.33°N	47.27°N - 47.37°N	39.60°N - 39.84°N
Extent (Longitude)	116.67°W - 116.88°W	121.44°W - 121.62°W	123.49°W - 123.74°W
DEM resolution (m)	1	1	1
Coordinate system (Horizontal)	UTM Zone 11N NAD83(2011) [EPSG: 6340]	UTM Zone 10N NAD83 (2011) [EPSG: 26910]	UTM Zone 10 N NAD83 (CORS96) [EPSG: 26910]
Coordinate system (Vertical)	NAVD88 (Geoid 12A) [EPSG: 5703]	NAVD88 (Geoid 03) [EPSG: 5703]	Ellipsoid (GRS80)

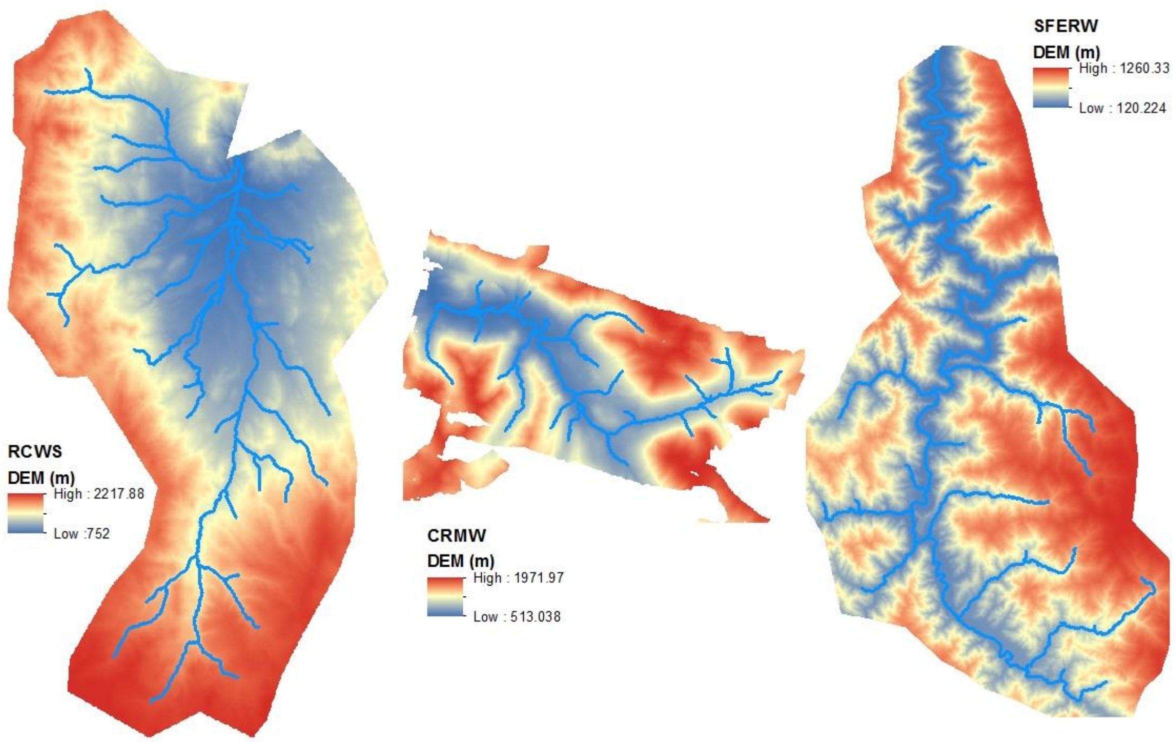


Figure 1: The 1m DEMs for the RCWS, CRMW, and SFERW study sites overlaid with their corresponding reference drainage network.

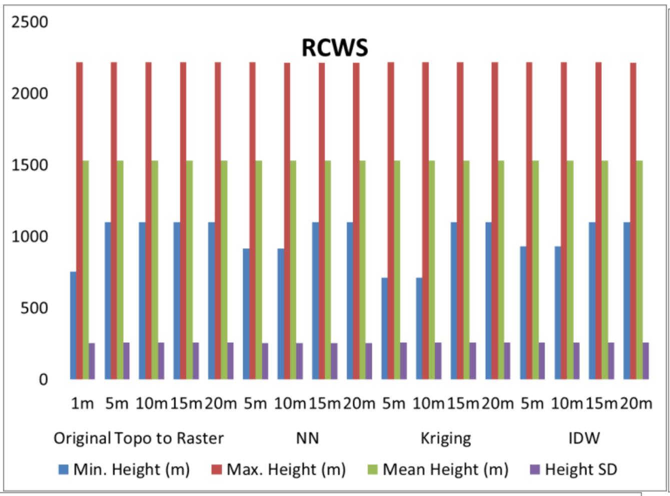
2.4 Data Processing and Analysis

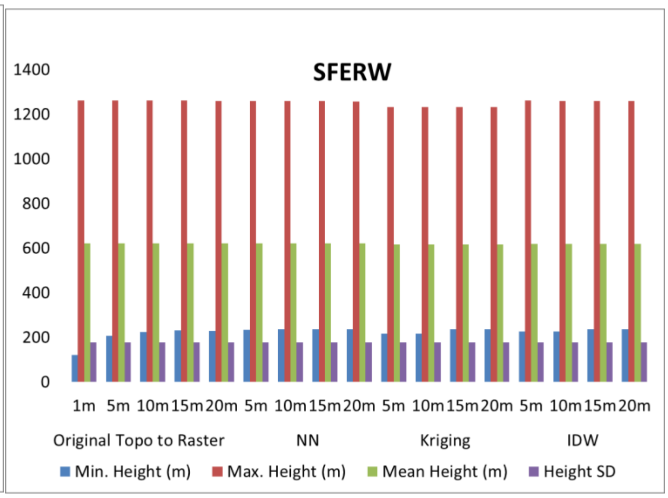
This study is basically an assessment of the impact of DEM resolution and interpolation techniques on the accuracy of the extracted drainage network with respect to the different nature of the terrain and based on the heights data extracted from existing high-resolution DEM. Doing this, the extraction of points of a degree of importance from the height data before interpolating the DEMs at different resolutions, extracting the drainage network, and then assessing the accuracy of the extracted drainages. Nevertheless, before the points extraction for the assessment in the SFERW, the coordinate transformation was conducted to UTM Zone 10N NAD83 (2011) [EPSG: 26910] from UTM Zone 10 N NAD83 (CORS96) [EPSG: 26910] to enable the elevation data to be above the Geoid not Ellipsoid (Eteje et al. 2018). This is because; the original heights were ellipsoidal heights, not geoidal heights and the other data for this study are above the geoidal surface, not the ellipsoid surface.

3.1 RESULTS AND DISCUSSION

The interpolated DEMs for each of the methods at all the sites appear to have not much difference in their mean heights, maximum heights, and elevation standard deviation from the original data, but substantial variation was observed in the minimum height values. The minimum values for all the Topo to raster DEMs are approximately the same at RCWS, though they vary in the other two sides and have much higher values than those of the original DEM at all the sites. This result from the use of drainage enforcement algorithm in the Topo to raster methods that removes all sink points in the original data by replacing them with the lowest adjacent saddle point (Hutchinson et al., 2011). This implies that the minimum values in the original data might be the values of the sink. The minimum values in the other methods are similar for 5 and 10m and 15 and 20m for most of the methods at all the sites. This shows that 5 and 10m DEMs produced DEMs with similar statistics, likewise, 15 and 20m DEMs. It is difficult to ascertain the reason behind that, but one factor is most likely to be the reason, which is the point density (Setianto and Triandini 2013). The density of the points used might not be sufficient enough to capture the sharp variation at a resolution below 10m in all the study sites (Jakubowski et al., 2013). The variations were able to be identified at 10m resolution even for the areas with low points density (gentle slope areas) because of the multiscale representation allowed by the TIN, where steep slopes have smaller triangles with high-density spot heights while gentle slope areas have large triangles with low-density spots height. However, Ajvazi and Czimber (2019) argued that the density of sample points does not have a linear impact on the accuracy of the interpolated DEMs.

The 5m DEMs could be more influential in the surface estimation if more suites of hydrologic constraints other than streamlining vertices are used with the TIN nodes, because it can enable the preservation of more hydrologically essential details from the original DEMs or the study sites and can reasonably increase the point's density.





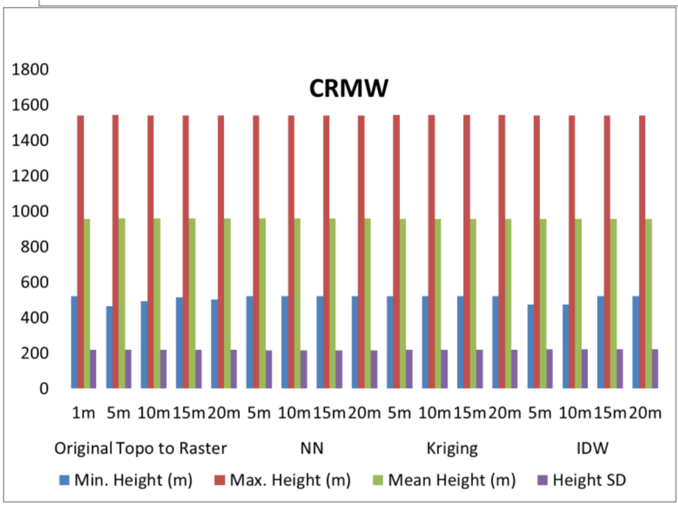


Figure 2: *the statistics of all the interpolated DEMs (Topo to Raster, N.N., kriging and IDW) of the three study areas (RCWS, SFERW, CRMW) at 5, 10, 15, and 20m resolutions*

Despite the variation in RMSE values between the methods at all the sites (Table 2), the RMSEs remain approximately the same within all the methods, except in Topo to raster DEMs at RCWS. This is because the point data manages to capture most of the surface characteristics in such a way that small changes in resolution cannot easily alter the accuracy, even though it is a fact that accuracy decreases with a decrease in resolution (Thomas et al. 2017).

The best performance observed by the N.N. method at all the sites and resolution is likely due to the few visual artifacts present on the produced DEMs (Abramov and McEwan 2004 and Bater and Coop 2009) and was not affected much by terrain type, provided that points of a degree of importance are used. Kriging performed better than IDW at all the sites, similar to what was obtained in several studies that compare the performance of IDW and kriging (Ajvazi and Czimber 2019, Arun 2013, and the reasons were clearly stated there.

The status of the Topo to raster method as the best method, as observed by Debella-Gilo (2016), was not maintained in this work, although it is the second-best performing method in the steeper and moderate slope sites (SFERW and CRMW, respectively).

Table 2: RMSEs of the interpolated DEMs

		DEMs RMSEs (m)			
Study Site	**Resolution (m)**	**Topo to Raster**	**N.N.**	**Kriging**	**IDW**
RCWS	5	7.03	4.91	6.63	12.45
	10	7.22	4.94	6.67	12.39
	15	15.68	4.83	6.54	12.29
	20	18.01	4.99	6.79	12.31
SHOW	5	7.54	5.39	16.15	12.34
	10	7.70	5.45	16.22	12.54
	15	7.68	5.66	16.34	12.66
	20	8.04	5.99	16.56	12.98
CRM	5	8.10	4.37	13.34	22.28
	10	8.47	4.60	12.68	21.91
	15	8.35	4.91	12.86	22.67
	20	8.74	4.76	13.11	22.35

The total lengths of all the streams of each of the extracted networks, at RCWS and SFERW, are shorter than those of the corresponding reference networks (Table 3). This might be the result of the extra streams identified in the reference networks that are not in the extracted networks. The accuracy of the streams length estimation for most of the DEMs at all the sites increases with an increase in streams order (Table 4).

Table 3: Summary of the generated networks for all the study sites

Study site	**Resolution**	**Topo to raster**		**N.N.**		**Kriging**		**IDW**	
		Length (m)	**No.**	**Length (m)**	**No.**	**Length (m)**	**No.**	**Length (m)**	**No.**
RCWS	**Original (1m)**	**146857.9 (65)**							
	5	97952.67	61	98796.59	57	126961.9	57	132525.4	65
	10	97120.14	59	98548	57	122475	65	136935	61
	15	97225.65	59	98713	56	124087	59	130869	61
	20	101310.2	63	97639	54	131420	68	131419	65
CRM	**Original (1m)**	**53564.18(54)**							
	5	44887.26	52	45207.1	43	59172.99	85	57627.32	81
	10	44507.15	46	45173.76	48	82790.18	165	55101.56	85
	15	45483.93	52	45237.21	44	90183.06	201	52723.86	77
	20	45493.04	52	44848.14	46	80877.69	167	53882.43	80
SHOW	**Original (1m)**	**98923.87(53)**							
	5	89356.1	53	89470.29	51	96032.5	63	94720.9	55
	10	88337.3	53	88780.88	53	97212.1	75	92158.7	55
	15	87591.51	57	88526.21	51	129379.8	135	91470.79	61
	20	87016.88	55	87634.55	51	104869.6	96	90910.22	55

Table 4: Accuracy assessment result for Streams length estimation

		Topo (accuracy (%))				NN (accuracy (%))				Kriging (accuracy (%))				IDW (accuracy (%))			
Study site	**Resolution**	**1**	**2**	**3**	**Overall**	**1**	**2**	**3**	**Overall**	**1**	**2**	**3**	**Overall**	**1**	**2**	**3**	**Overall**
RCWS	**5**	56	71	80	69	61	70	84	71	77	79	*81	79	78	*82	84	81
	10	52	84	85	74	59	74	84	72	76	76	*87	80	84	*92	*98	91
	15	60	61	79	67	58	76	82	72	87	76	75	79	75	*80	92	82
	20	59	83	78	73	56	78	82	72	79	*83	87	87	72	*80	99	84
CRM	**5**	87	72	80	84	88	73	81	84	*97	**	96	*90	96	**	84	*92
	10	87	69	80	83	83	99	80	84	**	**	84	**	93	**	86	*97
	15	90	71	79	85	83	99	80	84	**	**	77	**	100	**	56	98
	20	88	82	79	85	88	69	80	84	**	**	69	**	98	*53	62	*99
SHOW	**5**	88	*98	86	90	92	91	88	90	*94	*68	70	97	95	90	99	96
	10	90	93	86	89	91	90	88	90	*87	*53	56	98	96	83	95	93
	15	86	100	86	89	91	89	88	89	*71	**	**	*69	84	*92	94	92
	20	85	99	85	88	90	89	87	89	*66	**	**	*94	87	*96	92	92

('*' indicates overestimation while '**' indicates less than 50% accuracy)

The overall streams length estimation accuracies for all the sites have shown varying results, irrespective of resolution. This makes the best performing DEMs not from the highest resolution DEMs at all the sites (RCWS, IDW 10m; CRMW, IDW 20m; and SFERW, kriging 10m). This was not consistent with the results of Yang et al. (2014), that show decreasing tendency in total stream length as a function of cell size. However, it further proves that estimation of hydrological parameters depends not only on the accuracy of the data source and the DEM resolution (Vaze et al., 2010), but also on the behaviour of the interpolation method and nature of the terrain.

Even with the best overall accuracy by the IDW 10m at RCWS, overestimation of length was observed in the third order of all IDW networks, leading to the error of commission. The overestimation might be the result of the excessive meanders in the modelled streams, which prevent them from following the stream centerline and result in a length overestimation. However, Topo to raster and kriging DEMs are not suitable for streams length estimation, based on their low performances for this task.

The overall accuracy of stream number estimations across all interpolated DEMs and for CRMW and SFERW has shown that Topo to raster (5, 10, and 15m) are perfect for streams number estimation (Table 5). Even though IDW performed well at RCWS, DEMs of this method performed worst for this task at the other two sites. This makes the method and kriging not suitable for streams number estimation. Overestimation of streams number was primarily observed in the IDW and kriging networks. This might be due to the 1% maximum flow accumulation threshold used, which might be unsuitable for the methods (Amatulli et al., 2018).

Table 5: Accuracy assessment result for Number of Streams estimation

Study site	Resolution	Topo 1	Topo 2	Topo 3	Topo Over all	N.N. 1	N.N. 2	N.N. 3	N.N. Over all	Kriging 1	Kriging 2	Kriging 3	Kriging Over all	IDW 1	IDW 2	IDW 3	IDW Over all
RCWS	5	94	94	56	81	88	81	75	81	88	81	69	79	100	94	81	92
	10	91	100	63	84	88	88	69	81	100	81	94	92	94	94	75	88
	15	91	94	63	82	88	81	69	79	91	88	69	82	94	88	100	94
	20	97	87	69	84	85	81	63	76	94	87	81	87	100	87	69	85
CRM	5	96	80	90	96	79	80	81	80	**	**	*76	**	*50	**	*81	*54
	10	85	80	86	85	89	*80	81	89	**	**	**	**	**	**	*81	*50
	15	96	*80	90	96	82	80	81	81	**	**	**	**	*57	**	81	*57
	20	96	80	90	96	85	80	86	85	**	**	**	**	*54	**	76	*52
SHOW	5	100	100	100	100	96	89	100	96	*70	**	82	*81	*96	100	*94	*96
	10	100	100	100	100	100	100	100	100	**	**	71	*58	*96	100	*94	*96
	15	*93	*89	*94	*92	96	89	100	96	**	**	*76	**	85	*67	*94	*85
	20	*96	*89	100	*96	96	89	100	96	**	**	94	**	*96	*89	100	*96

('*' indicates overestimation while '**' indicates less than 50% accuracy)

The LRMSE values (Table 6) has shown that the extracted networks for each of the interpolation method have different LRMSE values from one another, leading to the estimated values between 25.09m (N.N. 10m) and 104m (IDW 10m) at RCWS; 13.83 (N.N. 5m) and 274m (kriging 10m), at CRMW; and 23.15 (N.N. 10m) and 290.08m (kriging 5m), at SFERW. These values are very high, similar to result obtained by Yang et al. (2014) for RCWS. Nevertheless, interestingly, N.N. extracted networks are the only networks that show consistency at all the resolutions and for all the sites, showing virtually the same accuracy level as observed by Yang et al. (2014) that uses denser and highly accurate data. Similar consistency by this method was also found in stream length, number, and density estimations and even in the DEM RMSE. These show that the accuracy of N.N. DEMs and derivatives do not rapidly change with change in resolution, especially between 5 and 20m at all-terrain type. More importantly, the consistency of this method in the estimation of the hydrological parameters was inherited from the DEM elevation prediction. This is because the vertical accuracy of elevation data is just as critical as cell size since a small error in the elevation can result in totally different and incorrect model predictions (Vaze and Teng, 2010).

Table 6: LRMSE table

TERMS (m)					
Study Site	**Resolution**	**Topo to raster**	**N.N.**	**Kriging**	**IDW**
RCWS	**5**	56.37	25.17	46.85	100
	10	38.89	25.09	66.8	104
	15	63.67	25.74	87.41	90
	20	60.05	25.61	92.2	91
CRM	**5**	61.00	13.83	94.20	65.13
	10	44.20	14.86	274.94	21.44
	15	67.15	15.81	196.53	45.56
	20	60.68	16.02	82.73	24.55
SHOW	**5**	58.44	23.28	290.08	55.48
	10	44.77	23.15	272.65	78.40
	15	46.10	23.39	197.40	53.16
	20	55.84	23.94	140.77	51.17

The 10m networks produced most of the best and the worst simulation in terms of LRMSE. This shows that the interpolation method can be identified as good or not for a particular task at this resolution. This finding is both in line with the findings of Anderson (2012), who showed that 10 m LiDAR-DEM modelled hydrological parameters produces the closest result to field observations; and the proposal by Yang et al. (2014), who proposed that a 10m grid cell size represents a rational compromise between increasing resolution and data volume for simulating geomorphic and hydrological processes. It also goes in line with the outcome of Anderson (2012) that found that the best fit between the modelled stream networks and reference data occurred not at the most satisfactory resolution but rather with cell size in the range of 5 to 10 m.

The assertion by Yang et al. (2014) that LRMSE increases with cell size were only observed in the kriging (at RCWS) and N.N. (at CRMW) networks, with the remaining networks not showing a particular pattern.

Therefore, this shows that their findings depend not only on interpolation method and terrain type but also on additional factors, like data source (Anderson, 2012), to be true. Since they used one of the study sites (RCWS), such assertion was confirmed in only one interpolation method. However, most of the results at RCWS were similar to those of Yang et al. (2014), which further affirm their assumption that "similar results would be achieved using DEM's derived from other data sources".
The results of the drainage density estimations (Table 7) have shown very different values for all the methods but with a bit of consistency within the Topo to raster, N.N., and IDW networks at all resolutions. Therefore, this shows that the interpolation method has a more significant impact on drainage density estimation than resolution. However, both the resolution and interpolation methods affect accuracy. The result has also shown that drainage density estimation accuracy has no specific pattern of occurrence in terms of resolution because, for every method, the different resolution provides the best estimation, but the overall assessment has shown that IDW 10m has the best estimation (93% accuracy) while N.N. 20m has the lowest accuracy (66%). This clearly shows that the spatial accuracy of the interpolated DEMs has an insignificant impact on the accuracy of drainage density estimation because N.N. 20m is among the DEMs with less than a meter accuracy discrepancy from the most accurate interpolated DEM (Table 2). Furthermore, the best interpolated DEM (N.N. 10m) is also the least performing in terms of stream density estimation.

Table 7: Drainage density estimation accuracy assessment results

		Topo to Raster		**NN**		**Kriging**		**IDW**	
Study site	**Resolution**	**Density (km/km^2)**	**Accuracy (%)**	**Density (km/km^2)**	**Accuracy (%)**	**Density (km/km^2)**	**Accuracy (%)**	**Density (km/km^2)**	**Accuracy (%)**
RCWS	**5**	0.39	66	0.4	68	0.51	86	0.53	90
	10	0.39	66	0.4	68	0.49	83	0.55	93
	15	0.39	66	0.4	68	0.5	85	0.53	90
	20	0.41	69	0.39	66	0.53	90	0.53	90
CRM	**5**	0.78	84	0.78	84	1.02	*90	0.99	*92
	10	0.77	83	0.78	84	1.43	*45	0.95	*97
	15	0.79	85	0.78	84	1.56	*32	0.91	98
	20	0.79	85	0.77	84	1.40	*49	0.93	*99
SHOW	**5**	0.60	90	0.60	90	0.64	97	0.63	96
	10	0.59	89	0.59	90	0.65	98	0.62	93
	15	0.59	89	0.59	89	0.87	*69	0.61	92
	20	0.58	88	0.59	89	0.70	*94	0.61	92

RCWS has the density of $0.59km/km^2$; CRMW has the density of $0.92km/km^2$; and SFERW has the density of $0.66km/km^2$. '*' indicates overestimation.

4.1 CONCLUSION

This research used points extracted from high-resolution DEM (1m) to investigate the impact of resolution, interpolation method and topography on the accuracy of drainage network. The accuracy assessment was conducted using the length of streams, drainage density, and LRMSE. Each assessment method yielded a different result, and the decision on which result to use depends on the area of application of the extracted network's parameters. For applications that depend on the stream length and number estimation accuracy (width function estimation) and aquifer discharge and breadth estimation, the length and streams number assessment can be valuable. For applications that require the positional accuracy of streams, like flood risk modelling and streamflow forecasts Yang et al. (2014), the LRMSE assessment can be helpful. The density assessment results can be helpful for applications that depend on drainage density accuracy (Rainfall-runoff and peak discharge estimations.
Two different DEM resolutions (10 and 15m) and methods (IDW and kriging) were identified as the best representation of the stream lengths at all three sites showing the dependency of length estimation on topography. However, the contradictory behaviour of kriging DEMs in the estimation of lengths (both best and worst) in areas dominated by steep slopes (SFERW) makes the method suspicious and cannot be recommended for length estimation in such type of terrain. IDW 5m has 96% accuracy of estimation in this area, and none of the DEMs from this method show accuracy below 90% at the site. Therefore, for areas dominated by steep slopes (SFERW), IDW 5m is recommended. For the areas dominated by the gentle slope (RCWS), IDW 10m can produce reliable results; and for areas with moderate slope (CRMW), IDW 15 can

yield the most reliable result. In general, IDW DEMs are very reliable for streams length estimation.

The accuracy of the estimated streams numbers is higher in the lower streams order and lower in the higher-order, showing an inverse relation compared with the stream's length in most of the sites. Overestimation of streams number was primarily observed in the IDW and kriging networks, making them unsuitable for the task. Resolution seems to have less impact on the accuracy of streams number estimation, owing to the similar performances of DEMS of different resolutions in the streams number estimations. Irrespective of topography, Topo to raster DEMs between 5 and 20m has shown excellent performance at all the sites even though the method did not produce the overall best in one of the sites.

Both resolution and interpolation methods affect the accuracy of drainage density estimation, and the accuracy has no specific pattern of occurrence in terms of resolution. The choice of method and resolution for drainage density estimation for any terrain type is the same as that of stream lengths. This is because density is a function of length and watershed area. Therefore, the same recommendation is given here as that of length estimation.

The LRMSE of a drainage network depends on resolution, topography, and the accuracy of the DEM used. DEMs of different methods provide different results at both the same and different sites. DEMs of the same method also produce different results at both the same and different sites. However, N.N. DEMs have shown similar results at each site, making the method the most appropriate for operations requiring accurate stream positioning. The recommended method and resolution for any terrain is N.N. 10mowing to its overall performance in two of the sites and the similar result by the DEM with the overall best in the other site.

Finally, the conclusion presented here is based on comparing the results with reference data produced from 1m DEM, which might not be exact in all ramifications as the data in the field. The flow routing algorithm used in this assessment has its weaknesses, which might contribute to the low performance of some of the methods. Furthermore, the classification of the study sites was based on the physical appearance and the spatial distribution of the extracted points, not on any specific theory or concept; hence it might not be correct. Therefore, a bit of cautiousness has to be used when making decisions related to the conclusion of this work. However, whenever the final output resolution is decided by an analyst for any particular application of drainage network, the accuracy assessment tables provided in this work can be used to determine the best combination of method, topography and resolution to use.

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