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Research Article

Morphometric analysis and prioritization of watersheds for soil erosion management in Upper Gibe catchment

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Abstract: As morphometric investigation is connected to prioritization of watershed, morphometric analysis has got a significance role in light of soil and water conservation. In this study, an endeavour for the examination of point by point morphometric analyses of sub-basins was accomplished through the measurement of linear and shape parameters by using ArcGIS-9.3 software. Specifically, linear and shape morphometric parameters like stream length, stream order, drainage density, stream frequency, bifurcation ratio, Length of overland flow, basin perimeter, form factor, compactness coefficient, elongation ratio has been considered. The SRTM DEM (30 x 30 m) is processed for the delineation resulting in 61 sub-basins. The morphometric parameters which affect the soil erodibility are considered to organize the sub-basins and relegate positions on the premise of their association with erodibility to get compound parameter (Cp) esteem. Based on the value of Cp the sub-basin with the lowest Cp value was given the highest priority and then categorized the sub-basins into three classes as high, medium and low in terms of priority. Accordingly, high priority zone comprises 11 sub-basins, medium 19 and low 31 sub-basins. The sub-basins which are falling under high priority were a great deal more defenceless to soil disintegration and ought to be given high need for land preservation measures.

Keywords: *ArcGIS, compound parameter, morphometric parameter, prioritization*

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Introduction

Natural resources like land, water and soil are normally depleting day by day, due to their wide utilization with increasing population, industrialization and urbanization, demanding planning and management of these resources for sustainable development (Ahmed and Rao, 2015). The managerial system in turn requires examination of a drainage basins and sub-basins to conserve natural resources. Effective watershed management should recognize the interrelationships among the linkages between uplands, low lands, land use, geomorphology, slope and soil and then highlights the management techniques to control erosion in the watershed area. Water erosion is a major part of land degradation that influences the physical and chemical properties of soils and resulting in on-site nutrient loss and off-site sedimentation of water resources in arid and semi-arid areas of Ethiopia. Handling nearby impacts of soil disintegration requires comprehension of the rates of soil misfortune and also recognizable proof of the major controlling variables that upgrade or retard these procedures (Brhane and Mekonen, 2009). Morphometric analysis of a watershed provides a quantitative description of the drainage system, analysis of form and a concept that encompasses size and shape which is an important aspect of the characterization of watersheds (Strahler, 1964). This helps to elaborate a primary hydrological diagnosis in order to predict approximate behavior of a watershed if correctly coupled with geomorphology and geology

(Angillieri, 2008). Hence, morphometric analysis of a watershed is an essential first step, toward basic understanding of watershed dynamics. Watershed prioritization is the ranking of different sub watersheds of a watershed according to their vulnerability to soil erosion. This analysis can be achieved through measurement of linear and shape aspects of basins with the aid of Geographic Information System (GIS). GIS techniques are currently used for assessing various terrain and morphometric parameters of the drainage basins, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information. A quantitative morphometric characterization of a drainage basin is considered to be the most satisfactory method for the proper planning of watershed management because it enables the user to understand the relationship among different aspects of the drainage pattern of the basin, and also to make a comparative evaluation of different drainage basins developed in various geologic and climatic regimes (Zende et al., 2013). In specific terms, results of river morphometric analysis yield useful information pertinent to the ruggedness of the terrain, irrigation potential of the basin, flood risks control and above all, it provides an input for understanding the role of the physical characteristics of the terrain in development of the drainage basin (Vandana, 2013). Degradation of cultivated land is a big challenge in Ethiopia for many years and is sever in Upper Gibe. Particularly, land sliding, reservoir sedimentation and degradation of soil are among the major problems. To manage this problem prioritization of watershed based on morphometric parameter is considered in this study so as to contribute something in problem solving of the Upper Gibe watershed. Therefore, this study was taken to use conventional morphometric analysis of the watershed for its ability to assess vulnerability of watersheds by prioritization of sub watershed for soil conservation practice using Arc GIS 9.3 software.

Materials and Methods

Study area

Upper-Gibe watershed is found in the Omo Gibe River basin at the south-western part of Ethiopia, in Oromia Regional state with total area of 33,620 km^2 (Figure 1). The Omo Gibe River Basin is the second largest river system after that of the Blue Nile which, accounting for 14% of Ethiopian annual Runoff. It flows from the northern highlands through the lowland zone to discharge into Lake Turkana at the Ethiopia/ Kenya border in the south.

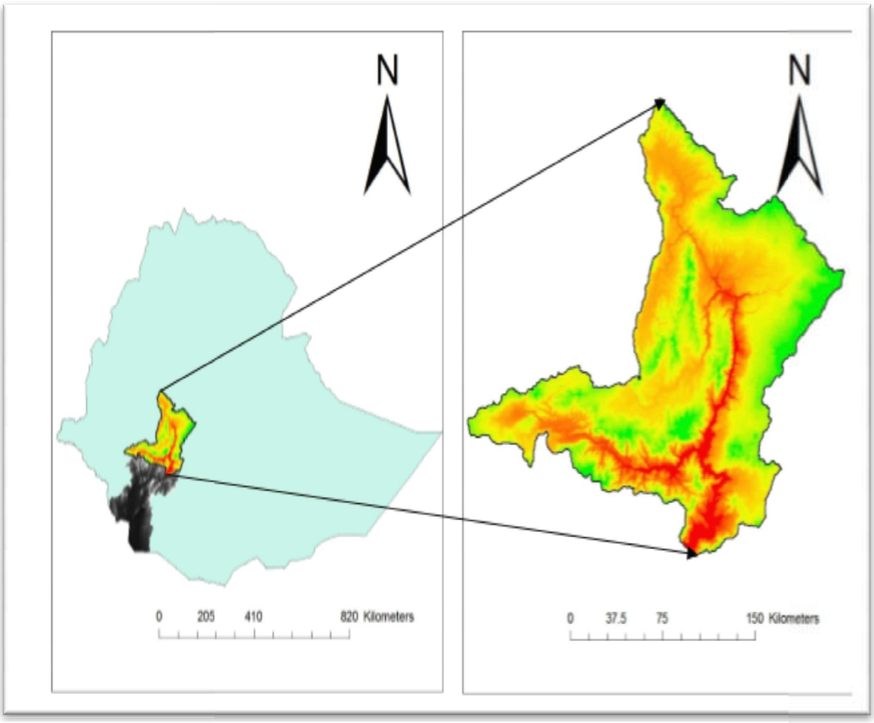

Figure 1. Location of the study area

Methodology

Digital elevation model (DEM) of 30m by 30m was used for watershed delineation and characterization with outlet near the Gilgel Gibe III dam. Stream channels were defined as DEM cells having at least a 500 hectare contributing area. The contributing area resulted in 61 sub-basins being delineated. Information reviewing from the literature supported with ground truth collection through focus group discussion and informal discussions were held to support and verify primary data's for the analysis. Finally, Arc GIS 9.3 software was used to analyse morphometric parameter and prioritize the watershed. In morphometric analysis both linear and shape parameters were used for the sub basin prioritizations. Stream Order (u), Stream Number (Nu), Stream Length (Lu), Mean Stream Length (Lsm), Drainage Texture (Dt), Length of Overland Flow(Lg), Bifurcation Ratio (Rb), Drainage Density (Dd) and Stream Frequency (Fs)were used in this study for linear parameters. Whereas Form factor (Ff), Circulatory ratio (Rc), Elongation ratio (Re) and compactness coefficient (Cc) were used for shape parameters. For prioritization of sub-basins, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. Similarly, the lowest value of shape parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. Finally, the ranking of the micro watersheds has been determined by assigning the highest priority based on highest value in case of linear parameters and lowest value in case of shape parameters (Nooka Ratnam et al., 2005).

Results and Discussion

Morphometric analysis of linear parameters

Stream number (Nu) and stream order (u)

Following Strahler's scheme, it has been found that in Upper Gibe Catchment the total number of streams are 1540, out of which 784 belong to 1st order, 376 are of 2nd order, 151 are of 3rd order, 134 are of 4th order, 41 of 5th, and 54 is of 6th order. The study reveals that the highest number of streams is found in sub-basin 53(103), followed by sub-basin (94) and sub-basin (70), whereas the smallest number of streams is found in sub-basin 15(1), 17(1), 45(1) and 55 (1). The first order streams were found to be the highest in number in almost all sub-basins which decreases as the order increases and the highest order has the lowest number of streams.

Stream length (Lu)

The stream length was computed based on the law proposed by (Horton, 1945) for all the sub-basins. From the result, the stream length decreases as the stream order increases in most of the sub- basins. This change may be due to flowing of streams from high altitude, lithological variations and moderately steep slopes.

Drainage texture (Dt)

The drainage texture depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development. Drainage textures can be classified into five classes i.e., very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8) (Smith, 1950). In the present study, the drainage texture values range from 0.06 to 1.17 per km, indicating that all the sub-watersheds fall under very coarse category of texture that indicates good permeability of sub-surface material and infiltration capacity, lower run off rate, and significant recharge of the ground water except the area occupied by the first order streams..

Length of overland flow (Lg)

Generally higher value of Lg is indicative of low relief and whereas low value of Lg is an indicative of high relief. The higher values of Lg infer the longer flow paths, less surface runoff and low relief with gentle slopes whereas lower Lg values indicate the shorter flow paths, high surface runoff and high relief with steep slopes. The computed values of Lo for all sub- basins range from 0.58 to 5.02 km.

Bifurcation ratio (Rb)

The bifurcation ratio (Rb) of the study area varies from 0 to 11, lower values of sub-watersheds suggest less structural disturbance, whereas higher values of sub- basins indicate structurally controlled drainage pattern. The mean bifurcation ratio may be defined as the average of bifurcation ratios of all orders (Strahler,1957). The mean Rb in sub-basins fluctuates from 0 to 2.45, and all the sub- basins fall under less structural disturbance.

Drainage density (Dd)

Based on the drainage density values, for the study area the value varies from 1.16 to 10.05 km/km^2. That means the sub watershed lays from low to high drainage density. It has been observed over a wide range of geologic and climatic types, that low drainage density is more likely to occur in regions of highly permeable subsoil material under dense vegetative cover, and where relief is low.

Stream frequency (Fs)

Generally if the sub-basins having large area under dense forest have low drainage frequency and the area having more agricultural land have high drainage frequency. High value of drainage frequency in sub-basin 55 produces more runoff in comparison to others.

Morphometric analysis of shape parameters

Form factor (Ff)

The values of form factor would always be less than 0.7854 (perfectly for a circular basin). In the present study, Ff values vary between 0.000017 to 0.155, suggesting that all sub- basins represent more or less elongated in nature with less side flow for longer duration. Flood flows of such elongated basins are easier to manage than the circular basin.

Circulatory ratio (Rc)

Circularity ratio is influenced by the length and frequency of streams, geological structures, land use/cover, climate, relief and slope of the basin. Higher the Rc value, higher is the flood hazard at the peak time at the outlet point. It also indicates that high Rc value of the sub- basins are more circular and are characterized by high to moderate relief and drainage system is structurally controlled while the lower Rc values of sub-watersheds indicate an elongated shape. In the present study, the Rc values for all sub-watersheds range from 0.000106 to 0.000579 which show that the sub- basins are elongated.

Elongation ratio (Re)

Values of Re close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are usually associated with high relief and steep ground slope (Strahler, 1964). In this study, all the sub-basins varies from 0.0046 to 0.4442, indicating that the sub-basins are more or less elongated or oval shape, characterized by high relief and steep slopes, high infiltration capacity and low runoff.

Compactness coefficient (Cc)

Compactness coefficient is directly proportional to the erosion risk assessment i.e. lower values implies less vulnerability for risk factors, while higher values indicates great vulnerability and represents the need of implementation of conservation measures. Lower values of this parameter indicate more elongation of the basin and less erosion, while higher values indicate less elongation and high erosion (Patel et al., 2012). The values of Cc in the study area vary from 41.53 to 96.95; showing high value with wide variations across the sub- basins indicates great vulnerability.

Prioritization of sub-watersheds

Prioritization of sub-basins is done to identify critical zone with high erosion activities so that appropriate conservation measures can be taken for minimizing soil erosion in the area. For prioritization of sub- basins, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. The lowest value of shape parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. Compound factor is computed by summing all the values of linear parameters as well as shape parameters and then dividing by number of parameters. Compound parameters values are calculated and the sub- basin with the lowest rank was given higher priority according to Vandana (2013). The prioritization was carried out by assigning ranks to the individual indicators and a compound value (Cp) was calculated. Sub- basin with highest Cp values has been low priority while those with lowest Cp values have been high priority. The sub-basins have been broadly classified into three priority zones according to their compound value (Cp) i.e. High (< 6.5), Medium (6.5-7.5) and Low (7.5 and above) (Figure 2).

1. **High Priority:** Highest priority indicates the greater degree of soil erosion in the particular sub-basin and it becomes potential area for applying soil conservation measures. The eleven sub-basins are grouped under high priority class should be provided with immediate soil and water conservation measures as they are likely to be subjected to maximum soil erosion.
2. **Medium Priority**: There are nineteen sub-basins falling in medium priority. These sub-basins are characterized by moderate slopes, high to moderate values of drainage density, stream frequency, drainage texture, form factor, circulatory ratio and compactness coefficient.
3. **Low Priority:** The thirty one sub-basins have come under the low priority with slight erosion susceptibility zone and may need agronomical measures to protect the sheet and rill erosion.

Sub-basins falling under high priority are under very severe erosion susceptibility zone. Indicating the need of an immediate attention to take up mechanical soil conservation measures like gully control structures and grass waterways to protect the topsoil loss. While sub-basins falling under low priority have very slight erosion susceptibility zone and may need agronomical measures to protect the sheet and rill erosion. Summary of the linear and shape parameter calculations and the prioritization rank of all the sub basins are indicated in the Table 1.

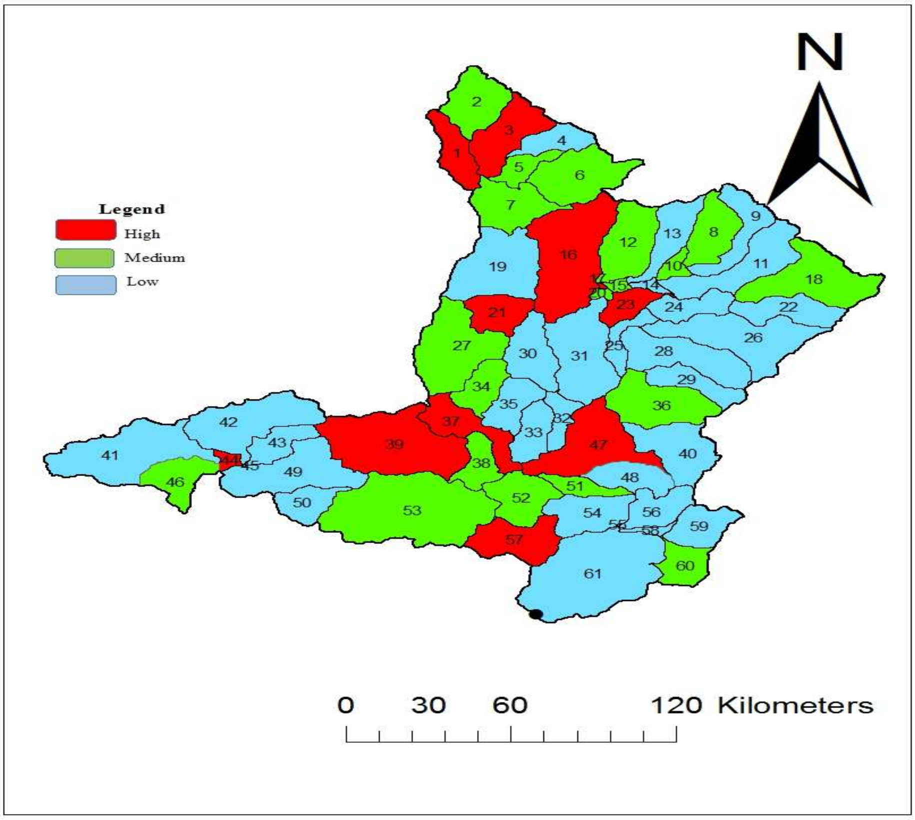

Figure 2. Final prioritization map

Conclusion

Watershed prioritization is a standout amongst the most essential parts of getting ready for usage of its improvement and administration programs. Morphological analysis utilizing GIS is quite accurate, reliable and easy over the conventional methods as GIS represents better spatial dissemination of topographic features on the map. Morphological analysis of the basin as one unit generates rough idea about topographic situations and its nature of runoff conditions. The analysis of drainage frequency on the various slope zones in basin gave the general idea about the rock foundation underneath in the basin. In addition, spatial distribution of sub-basin gives clear idea about distributed topographic condition of the basin and their resulted texture slope indices are quite helpful to identify erosion risk sites and soil conservation measure sites in relation to water resources management in the absence of other information. Thus, Watershed prioritization on the basis of morphometric parameters is essential in order to devise a sustainable watershed management plan. Immediate attention towards soil and water conservation measures are required in these sub-basins to preserve the land from further erosion and to reduce natural hazards possible due to erosion. The results indicate that the analysis of various morphometric parameters in GIS environment can be effectively used for prioritization of watersheds, soil and water conservation and natural resources management at the watershed level.

Based on the results of this study the following points are forwarded for further consideration:

1. Upper gibe is found on the Omo Gibe Basin, which contain Gilgel Gibe I, II and III mega projects. The sustainability of these projects are highly dependent on the condition of the upper reach as the maximum erosion would

be contributed from the upper reaches. Thus, great emphasis has to be paid in accurately quantifying soil erosion for that area.

2. According to the result of this finding, 11 sub-basins were under high priority that means more vulnerable for soil erosion. They need immediate conservation measures for minimize soil erosion from those areas.

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Table 1. Final prioritization Result of Gibe Basin

Sub Basin	Stream Frequency	Form Factor	Elongation Ratio	Circularity Ratio	Compactness Coefficient	Drainage Texture	Drainage Density	Length of Overland Flow Lg	Mean Bifurcation Ratio	Cp	Rank	Value
1	0.594	0.155	0.444	0.000	46.237	0.713	1.773	0.887	0.647	5.717	2	High
2	0.435	0.001	0.026	0.000	55.919	0.526	2.233	1.116	0.651	6.768	16	Medium
3	0.445	0.000	0.014	0.000	48.932	0.644	2.187	1.093	0.4	5.969	4	High
4	0.484	0.001	0.039	0.000	63.947	0.376	2.138	1.069	0.667	7.636	33	Low
5	0.487	0.000	0.009	0.000	58.054	0.356	2.119	1.059	1	7.009	22	Medium
6	0.446	0.000	0.014	0.000	54.520	0.647	2.165	1.083	1.379	6.695	15	Medium
7	0.626	0.000	0.008	0.000	58.223	0.737	1.968	0.984	1.8	7.149	26	Medium
8	0.457	0.001	0.029	0.000	57.959	0.499	2.541	1.271	0.693	7.05	23	Medium
9	0.409	0.000	0.008	0.000	91.155	0.273	2.214	1.107	0.733	10.66	60	Low
10	0.430	0.000	0.009	0.000	61.153	0.214	1.815	0.908	0	7.17	27	Medium
11	0.496	0.000	0.011	0.000	75.791	0.511	2.665	1.333	1.133	9.104	55	Low
12	0.402	0.000	0.024	0.000	57.672	0.509	2.398	1.199	0.67	6.986	21	Medium
13	0.369	0.000	0.009	0.000	80.662	0.277	2.368	1.184	0.225	9.455	58	Low
14	0.524	0.000	0.007	0.000	78.496	0.143	2.837	1.419	0	9.27	57	Low
15	0.196	0.000	0.007	0.000	61.062	0.065	2.251	1.126	0	7.19	28	Medium
16	0.433	0.000	0.008	0.000	48.922	0.929	2.179	1.089	1.7	6.14	7	High
17	1.389	0.000	0.010	0.000	47.278	0.222	4.235	2.117	0	6.139	6	High
18	0.489	0.000	0.009	0.000	61.578	0.695	2.224	1.112	0.618	7.414	30	Medium
19	0.494	0.000	0.005	0.000	70.833	0.613	2.103	1.052	0.714	8.424	49	Low
20	0.745	0.000	0.009	0.000	55.250	0.241	2.164	1.082	0	6.61	13	Medium
21	0.335	0.001	0.030	0.000	50.106	0.372	2.074	1.037	0.667	6.069	5	High
22	0.445	0.000	0.014	0.000	64.924	0.420	2.190	1.095	0.667	7.75	35	Low
23	0.547	0.000	0.012	0.000	53.889	0.458	1.878	0.939	0.7	6.491	11	High
24	0.558	0.000	0.005	0.000	67.376	0.431	1.966	0.983	0	7.924	39	Low
25	0.232	0.000	0.015	0.000	79.294	0.121	2.042	1.021	0.4	9.236	56	Low
26	0.435	0.000	0.011	0.000	72.331	0.552	2.459	1.230	1.133	8.683	53	Low
27	0.453	0.000	0.011	0.000	57.114	0.713	1.720	0.860	1.08	6.884	18	Medium
28	0.449	0.000	0.012	0.000	66.952	0.528	2.285	1.143	0.825	8.022	40	Low
29	0.378	0.001	0.035	0.000	67.850	0.303	2.321	1.161	0.8	8.094	41	Low
30	0.480	0.000	0.013	0.000	64.340	0.490	1.757	0.879	2.455	7.824	37	Low
31	0.483	0.000	0.006	0.000	71.188	0.597	1.922	0.961	0.575	8.415	48	Low
32	0.312	0.000	0.018	0.000	70.432	0.187	2.186	1.093	0.3	8.281	45	Low

Sub Basin	Stream Frequency	Form Factor	Elongation Ratio	Circularity Ratio	Compactness Coefficient	Drainage Texture	Drainage Density	Length of Overland Flow Lg	Mean Bifurcation Ratio	Cp	Rank	Value
33	0.199	0.001	0.035	0.000	63.500	0.166	2.314	1.157	0.267	7.515	31	Low
34	0.561	0.000	0.025	0.000	58.120	0.514	1.963	0.981	1.875	7.116	25	Medium
35	0.386	0.000	0.007	0.000	70.555	0.304	1.998	0.999	0.7	8.328	47	Low
36	0.446	0.000	0.011	0.000	61.160	0.576	2.362	1.181	0.486	7.358	29	Medium
37	0.289	0.000	0.017	0.000	53.513	0.347	1.975	0.987	0.35	6.386	9	High
38	0.351	0.003	0.063	0.000	58.055	0.302	1.862	0.931	0.24	6.867	17	Medium
39	0.500	0.000	0.009	0.000	52.037	1.014	1.978	0.989	1.026	6.395	10	High
40	0.332	0.000	0.010	0.000	68.512	0.360	2.152	1.076	0.647	8.121	42	Low
41	0.571	0.000	0.008	0.000	66.202	0.834	1.952	0.976	0.613	7.906	38	Low
42	0.389	0.000	0.007	0.000	72.441	0.467	2.093	1.047	0.635	8.564	52	Low
43	0.288	0.002	0.054	0.000	65.108	0.221	1.489	0.744	0.25	7.573	32	Low
44	0.438	0.000	0.010	0.000	54.765	0.187	1.157	0.579	0	6.348	8	High
45	8.621	0.000	0.010	0.000	49.504	0.529	10.0517	5.026	0	8.194	43	Low
46	0.443	0.000	0.018	0.000	57.844	0.448	1.842	0.921	0.66	6.908	20	Medium
47	0.487	0.000	0.009	0.000	46.365	0.910	2.040	1.020	1.127	5.773	3	High
48	0.638	0.001	0.042	0.000	73.079	0.487	2.597	1.298	1.589	8.859	54	Low
49	0.430	0.000	0.007	0.000	67.976	0.537	2.007	1.004	1.96	8.213	44	Low
50	0.521	0.001	0.028	0.000	71.613	0.371	2.152	1.076	0.65	8.49	50	Low
51	0.428	0.000	0.013	0.000	58.213	0.301	1.879	0.940	0.4	6.908	19	Medium
52	0.442	0.000	0.008	0.000	54.611	0.521	1.890	0.945	0.733	6.572	12	Medium
53	0.556	0.000	0.008	0.000	57.852	1.167	1.962	0.981	1.498	7.114	24	Medium
54	0.427	0.000	0.008	0.000	72.291	0.387	2.075	1.037	0.44	8.518	51	Low
55	12.500	0.000	0.021	0.000	69.608	0.453	6.038	3.019	0	10.18	59	Low
56	0.487	0.001	0.040	0.000	63.286	0.429	2.337	1.168	1.85	7.733	34	Low
57	0.525	0.001	0.027	0.001	41.530	0.866	2.027	1.013	1.867	5.317	1	High
58	0.501	0.000	0.005	0.000	96.954	0.113	4.545	2.272	0	11.6	61	Low
59	0.339	0.121	0.393	0.000	65.314	0.298	1.412	0.706	1.32	7.767	36	Low
60	0.431	0.000	0.023	0.000	55.074	0.412	2.321	1.161	0.82	6.694	14	Medium
61	0.525	0.000	0.007	0.000	68.225	0.918	2.131	1.065	1.942	8.313	46	Low