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SOIL EROSION ESTIMATION BASED ON GIS AND REMOTE SENSING FOR SUPPORTING INTEGRATED WATER RESOURCES CONSERVATION MANAGEMENT

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ABSTRACT
Soil erosion is a crucial environmental problem in the Manjunto watershed, Bengkulu Province, Indonesia. It has economic implications and environmental consequences. Assessment of potential soil erosion rate is useful in designing soil conservation strategies within the framework of integrated watershed management. Information obtained from *Remote Sensing* (RS) and *Geographic Information System* (GIS) framework supports decision makers in preparing more accurate spatial maps in less time and cost. The aim of this research is to assess the average annual rate of potential soil erosion in Manjunto watershed for each soil mapping unit using remote sensing data, namely–*Normalized Difference Vegetation Index* (NDVI) and Slope. The NDVI value obtained from satellite imagery processing while slope value obtained from Digital Elevation Model-Shuttle Radar Topographic Mission (DEM-SRTM) processing. The results showed that the eroded catchment area increased significantly. The average annual rate of potential soil erosion in Manjunto watershed in the year 2000 amounted to 3.00 tons $ha^{-1}year^{-1}$, while in the year 2009 there was a significant increase to 27.03 ton $ha^{-1}year^{-1}$. The levels of erosion hazard in soil mapping unit numbers 41, 42 and 47 are classified in the very heavy category. Soil mapping unit numbers 41, 42 and 47 should be a first priority in soil and water conservation activities.

Keywords: DEM-SRTM; GIS; NDVI; Remote Sensing; Soil erosion

1. INTRODUCTION

Unintegrated watershed management system might be lead to high soil erosion rate. Such practice has resulted in an increased of the number of critical watershed and critical land area in Indonesia significantly. The number of critical watershed is currently more than 62, while critical land areas cover approximately 30.2 million hectares, of which 23.3 million hectares are classified as highly critical category (Ministry of Forestry, 2010). The causes of high levels soil erosion rate include the use of land that is not in accordance with its carrying capacity, techniques of farming that do not correspond to the rules of conservation, high rainfall intensity, topography, as well as slope (Asdak, 2009; Arsyad, 2010).

Soil erosion is a natural process of soil material removal and transportation through the action of erosive agents such as water, wind, gravity, and human disturbance (Aksoy et al., 2009; Asdak, 2009; Cochrane & Flanagan, 1999; Kefi et al., 2009; Hacisalihoglu et al., 2010; Liu et al., 2001; Mongkolsawat, 1994).

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However, if the soil erosion is occurring faster than necessary due to human disturbance, it will cause negative impacts on the environment and the economy (Lal 1998; Ananda & Herath, 2003; Pimental et al., 1995; Kefi & Yoshino, 2010). The strategic efforts to reduce soil erosion is through soil and water conservation programs (Renard et al., 1997; Saha & Pande, 1993). Spatial data are necessary for planning, monitoring and evaluation of conservation activities (Honda et al., 1996; Ande et al., 2009; Saha et al., 1991). The complete spatial data with various scales can assist in preparing a variety of strategies for all organization levels and for determining the priority setting and location of conservation programs (Morgan, 1984; Arsyad, 2010; Asdak, 2009; Ananda et al., 2001).

Rapid developments occurring in the technology of Remote Sensing (RS) and Geographic Information Systems (GIS) provide a new approach to meet various demands related to the modeling of resources (Brough, 1986; Arnold et al., 1998; Barling & Moore, 1994; Saha et al., 1991; Lillesand, 1994; Honda et al., 1996) including soil and water conservation (Honda et al., 1996; Renard et al., 1997). Green (1992) stated that the integration of RS in a GIS database can reduce costs, and time as well as improve the detailed soil survey information. Therefore, the use of RS and GIS in watershed management would be very helpful to the managers in making the decisions.

Satellite data can be used for mapping, monitoring and estimation of soil erosion (Hazarika & Honda, 2001; Fistikoglu & Harmancioglu, 2002; Hammer et al., 1995; Arsyad, 2010; Asdak, 2009). The erosion mapping using GIS and RS has been conducted in many countries, such as those conducted by Spanner et al., (1982), which combined GIS with USLE (Ande et al., 2009) for soil erosion and loss assessment. Hazarika and Honda (2001) mapped the threat of erosion in Thailand to evaluate the conservation activities in Mae Ao watershed, northern Thailand. Ande et al. (2009) approach estimated the erosion by using Morgan and Finney Model (MMF) in Southwest Nigeria. Kevi and Yoshino (2010) using RUSLE, RS and GIS to estimate the hazards of erosion on agricultural productivity in Tunisia. However, erosion mapping studies have not been carried out extensively in Indonesia. Arsyad (2010) stated that the published soil erosion mapping was undertaken by Dames (1955) using USLE methods in the watershed of Central Java, which covers 1.6 million hectares. The use of GIS to evaluate land degradation was performed by Lanya (1996), in estimating soil erosion rate through identifying morphological changes in the soil in-situ (Arsyad, 2010).

The aim of this research is to evaluate the potential soil erosion rate in each Soil Mapping Unit on a watershed scale using E_{30} models. The result of this study is expected to be used as guidelines to determine the strategy and site selection in prioritizing soil and water conservation activities. The site selection model is based on the condition of land cover in study area.

2. METHODOLOGY

2.1. Location and Description of Study Area

The study area stretches from 02°10'30" to 02°30'15" South Latitude, and from 101 °5'30" to 107°35'00" East Longitude in the District of Mukomuko, Bengkulu Province, Indonesia (Figure 1). It covers an area approximately 79.581 hectares. The land cover is dominated by forests. Based on data from BMKG (Meteorological and Geophysical Agency) of Mukomuko, the average rainfall of the study area was 3,329.70 mm year^{-1} and average annual temperature of 23.0^{o}C. Based on the results of a survey conducted by Puslitanah Bogor in 1982, the most dominant soil type in research area is Endoaquepts, Udifluvents, and Eutrudepts.

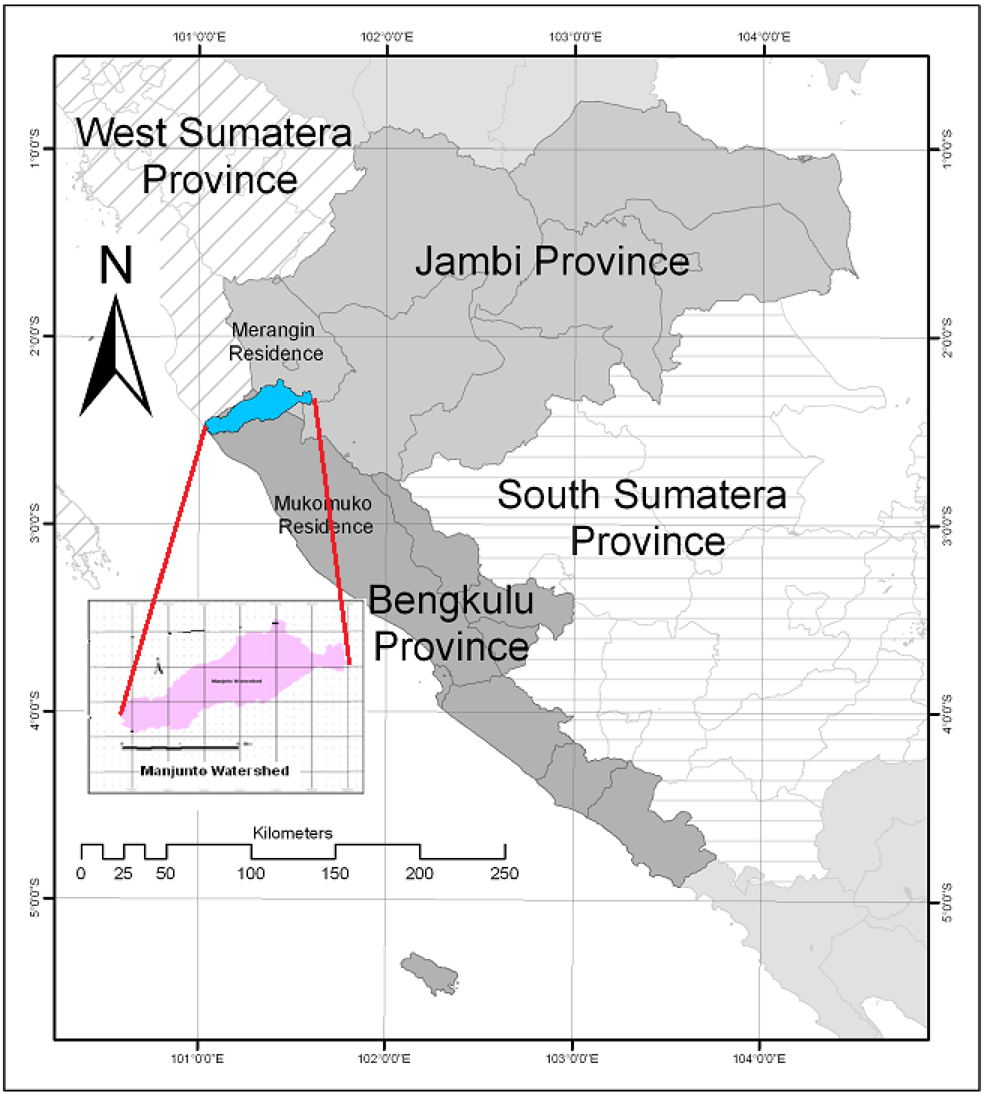


Figure 1 Study area

2.2. Digital Image Processing to Produce Land Cover Map

Analysis of land cover is based upon the interpretation of Landsat Thematic Mapper images (TM), the Landsat 7 (LS-7) ETM+ path 126/row 062, acquisition date in July 22, 2000 and Spot 4 path 355/row 271 acquisition date in May 17, 2009. Methods for the identification of land cover in this study using nearest neighbour Method. The types of land cover classes consisting of: 1) Forest, 2) Estates, 3) Dryland farming, 4) Farm/moor, 5) Bush, 6) Village, 7) Wetland farming, 8) Open land, and 9) Water bodies. The result of land classification is used to determine the sampling points in field activities. Delineation of the image generated based on the results of field inspection and land cover classification by using Nearest Neighbour Method, in order to obtain land cover map of Manjunto watershed in 2000 and 2009 year.

2.3. Soil Mapping Unit (SMU)

Soil mapping units used in this study were compiled with reference to the land unit and soil mapping of Sungai Penuh sheets, Sumatra; the mapping done by Puslitanah Bogor with a scale 1:250.000. Method of determining the class of each soil mapping unit according to the spreading of the dominant soil types in quantitative measures is grouped into five classes, namely: 1) Very dominant (P): if the spreading > 75% of soil mapping unit (SMU), 2) Dominant (D): if the spreading between 50-75% of SMU, 3) Enough (F): if the spreading between 25-49% of SMU, 4) Bit (M): if the spreading between 10-24% of SMU, and 5) Few (T): if the spreading <10% of SMU. Then the grouping and numbering of each soil map units were based on the most dominant spread of soil types at that location.

2.4. Estimate of Soil Erosion with E30 Model

To estimate the hazard of soil erosion that occurs in each soil mapping unit, the following equation is used (Hazarika & Honda, 2001):

$$E = E_{30}\left(S/S_{30}\right)^{0.9} \quad (1)$$

Where E: rate of annual soil erosion in the Manjunto watershed (ton ha^{-1}year^{-1}), S: gradient of the point under consideration (%), S_{30} = Tan (30^{o}), and E_{30}: the rate of soil erosion that occurs on a slope of 30^{o}, obtained using Equation 2 (Hazarika & Honda, 2001).

$$E_{30} = \exp\left[\left(\frac{LogE_{\min} - LogE_{\max}}{NDVI_{\max} - NDVI_{\min}}\right)\cdot\left(NDVI - NDVI_{\min}\right) + LogE_{\max}\right] \quad (2)$$

The maximum and minimum erosion values obtained from the data from Public Works Official of Bengkulu Province; E_{max} is 242 tons ha^{-1}year^{-1} and E_{min} is 0.1 tons ha^{-1}year^{-1}. NDVI can be calculated from the satellite image of the ratio calculations constructed from two spectral channels, namely spectral infra red (IR) and near infra red (NIR) (Huete, 1988; Honda et al., 1996). The general equation of NDVI is as follows (Honda et al., 1996; Hazarika & Honda, 2001; Panuju et al., 2009; Huete, 1998):

$$NDVI=(IR-NIR)/(IR+NIR) \quad (3)$$

If the channel, that recording infrared wave is Band 4 (B_4) and near infrared wave are Band 3 (B_3), so the Equation 3 can be changed as Equation 4. To avoid negative values and for easy handling of digital data, NDVI values are re-scaled, so the NDVI equation is as follows:

$$NDVI = \left[\left(\frac{B_4 - B_3}{B_4 + B_3}\right) + 1\right] x100 \quad (4)$$

Where, NDVI is a vegetation index that reflects the level of greenness of vegetation condition.

3. RESULTS AND DISCUSSION

3.1. The Slope Map

Slope map of DEM is processed with the help of Arc GIS 9.3 as presented in Figure 2. Data processed by GIS contains information on slope and the number of pixels or extensive information. Slope data is presented in Table 1.

The majority of the slope is more than 8%. The Slope factor will influence the speed and volume of surface runoff. Flat slope (0-8%) will provide more opportunities to the rain water to infiltrate, so that runoff volume will decrease. It will reduce runoff velocity so that its ability to erode and transport the soil would be less.

3.2. Soil Mapping Unit (SMU)

The results of class identification of each SMU by the spreading of the dominant soil types is presented quantitatively in Figure 3.

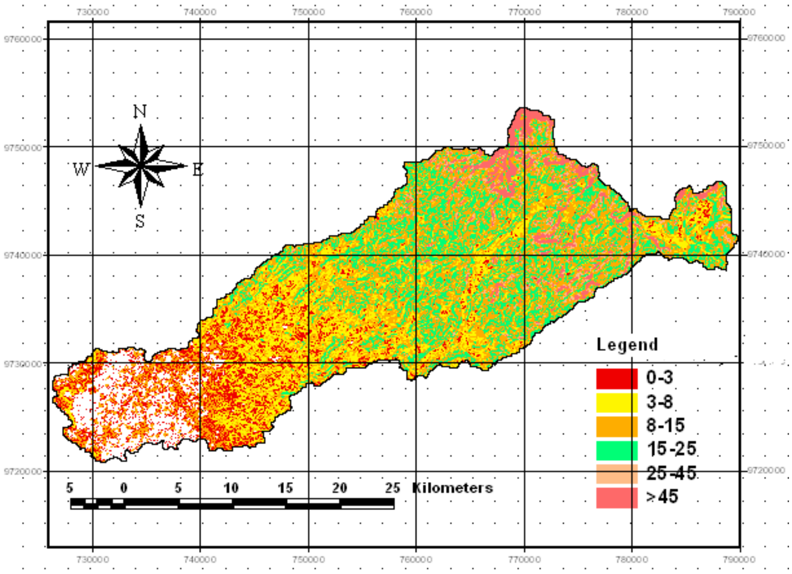


Figure 2 The slope map of Manjunto Watershed

Table 1 The slope of Manjunto Watershed

No.	Slope Class (%)	Area (Ha)	Percentage (%)
1	0 - 8	20,923.88	26.292
2	8 - 15	31,949.35	40.147
3	15 - 25	15,155.85	19.045
4	25 - 45	5,667.83	7.122
5	> 45	5,883.77	7.393
		79,580.678	**100.000**

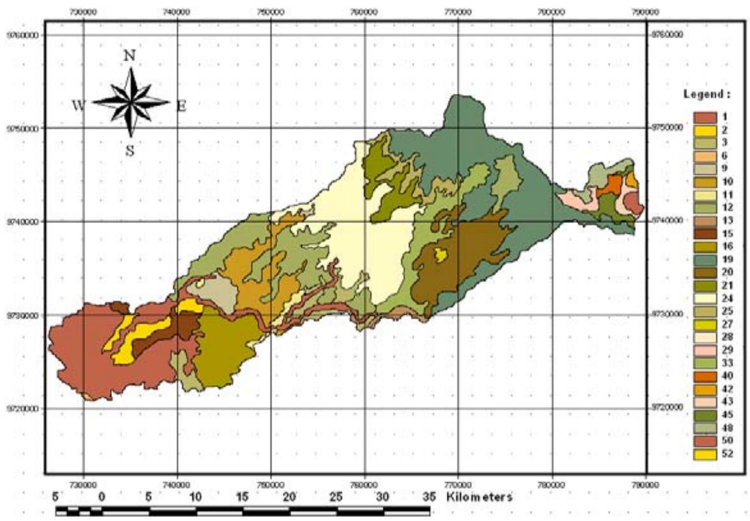


Figure 3 Soil mapping unit of Manjunto Watershed

3.3. Land Cover

Based on land cover identification in the year 2000 and 2009, the changing on every land cover class are presented on Figures 4 and 5.

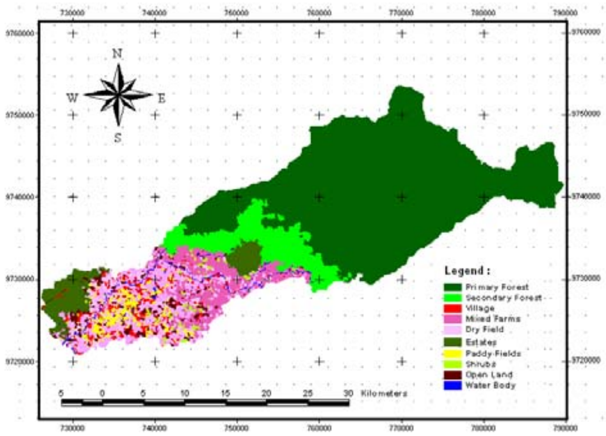


Figure 4 Land cover map 2000

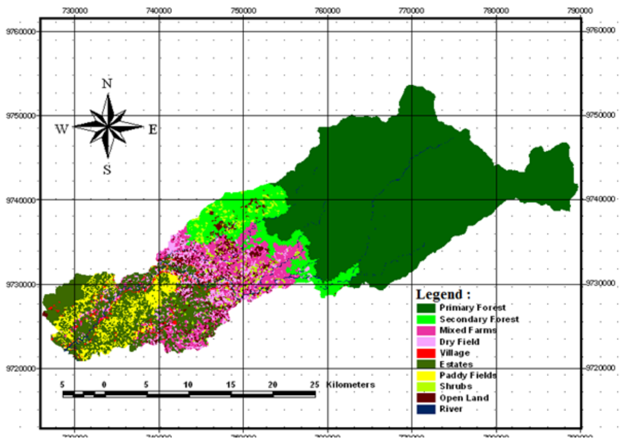


Figure 5. Land cover map 2009

The total forest area is reduced, while the plantation or estates areas are increased significantly. Changes in land cover were influenced by the local livelihoods since the majority of the people are farmers. The details of land cover conditions are shown in Table 2.

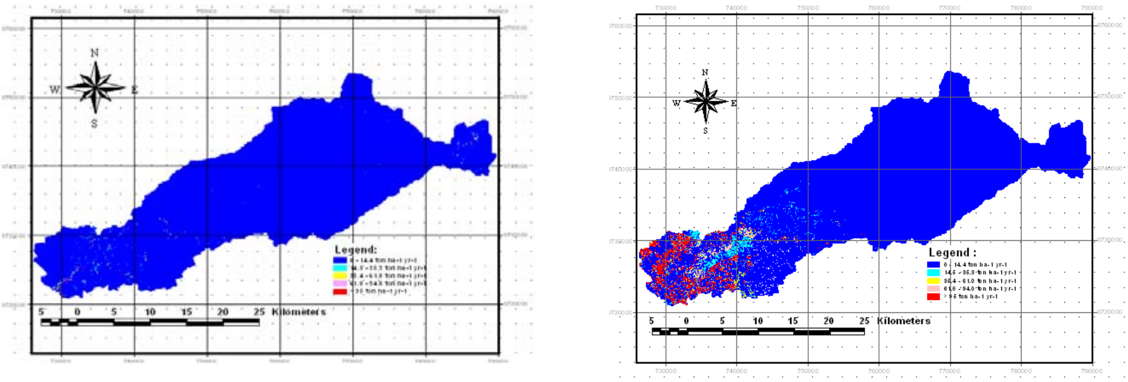
Table 2 Land cover of Manjunto Watershed in the year 2000 and 2009

No.	Land Used	Area (ha)		Difference	
		2000	2009	Area (ha)	Percentage (%)
[0]	[1]	[2]	[3]	[4]	[5]
1	Primary Forest	47,063.970	44,899.657	2,164.313	2.720
2	Secondary Forest	6,646.500	6,630.890	15.610	0.020
3	Mixed Farming	7,147.260	6,046.885	1,100.375	1.383
4	Dryland Farming	2,821.680	605.094	2,216.586	2.785
5	Estates	2,420.280	8,595.327	(6,175.047)	(7.759)
6	Bush	2,126.880	1,677.248	449.632	0.565
7	Wetland Farming	8,195.940	7,374.733	821.207	1.032
8	Roads	57.600	250.160	(192.560)	(0.242)
9	Water Body	925.650	929.865	(4.215)	(0.005)
10	Open Land	2,113.920	2,342.791	(228.871)	(0.288)
11	Village	61.110	228.140	(167.030)	(0.210)
	Total	**79,580.790**	**79,580.790**		

The information derived from Table 2 there has been a change in each type of land cover. The percentage of reduction of land cover in the area is the following: primary forest (2.72%), secondary forest (0.02%), mixed farms (1.383%), dryland farming (2.785%) and wetland farming (1.032%). On the other hand, there is increasing percentage in the following land cover: estate (3.041%), road (0.242%), open land (0.288%) and villages (0.21%). Changes in land cover are strongly influenced by socio-economic conditions and local culture. The main factors affecting changes in land cover is the source of income. Most of the people who live in Manjunto watershed are farmers.

3.4. Soil Erosion Mapping

The value of soil erosion occurs at each pixel is based on the results of calculations using Equation 1 presented in the form of annual potential soil erosion rate maps (Figure 6).



(a) (b)

Figure 6 Map of average annual erosion rate: a) year 2000, b) year 2009

From Figure 6 above it is known that the eroded watershed area in the year 2009 increased when compared with conditions in the year 2000. The total amount of land lost in Manjunto watershed in the year 2000 was mapped at 1,399,209 tons while in the year 2009 amounted to 23,004,391 tons. The annual average of potential erosion rate in the year 2000 was 3 tons ha^{-1}year^{-1}, and in 2009 was 27 tons ha^{-1}year^{-1}. High erosion occurs in the lower reaches of the basin's land use types, namely due to Dryland Farming. This factor causes the high rate of erosion in a way that the farming practice pays less attention to the rules of conservation, besides the high intensity of rainfall.

To determine the level of soil erosion that occurs in each SMU, the SMU map is overlaid to the soil erosion map. The results are presented in Table 3. The planning of soil and water conservation needs the information about the average annual rate of potential soil erosion on the soil mapping unit. The priority location can be selected based on the erosion hazard index value. Soil mapping unit that has the highest erosion hazard index will be the top priority for conservation. Therefore, the numbers 41, 42 and 47 of soil mapping unit are a first priority for conservation, whereas the numbers 40 and 45 in the soil map unit are the second one (see Table 3). The selection of conservation strategies should be adapted to the socio-economic conditions and local culture.

4. CONCLUSION

GIS and RS have been successfully to determine the potential soil erosion rate. The average annual rate of potential soil erosion in Manjunto Watershed in the year 2000 amounted to 3.00 tons ha^{-1}year^{-1}. It was an increase to 27.03 ton ha^{-1}year^{-1} in the year 2009. Some soil mapping units have levels of erosion hazard that are designated as being in very heavy category. These should be designated as a priority in soil and water conservation activities. To reduce the rate of erosion that is happening we need a system of sustainable agriculture and conservation management.

Table 3 The annual average erosion rate in soil mapping unit

SMU Number	The Mean Erosion (ton/ha/year)	Erosion Hazard	The Mean Soil Loss (mm/year)	Erosion Hazard Index	Class of Erosion Hazard Index
[1]	[2]	[3]	[4]	[5]	[6]
1	7.36	Very Low	0.74	0.28	Low
2	31.51	Low	3.15	1.19	Middle
3	7.89	Very Low	0.79	0.30	Low
6	25.64	Low	2.56	0.97	Low
9	0.13	Very Low	0.01	0.00	Low
10	0.48	Very Low	0.05	0.02	Low
11	0.36	Very Low	0.04	0.01	Low
12	0.11	Very Low	0.01	0.00	Low
13	0.59	Very Low	0.06	0.02	Low
14	1.22	Very Low	0.12	0.05	Low
15	0.17	Very Low	0.02	0.01	Low
16	0.17	Very Low	0.02	0.01	Low
19	1.17	Very Low	0.12	0.04	Low
20	1.42	Very Low	0.14	0.05	Low
21	0.15	Very Low	0.01	0.01	Low
24	1.79	Very Low	0.18	0.48	Low
25	0.03	Very Low	0.00	0.00	Low
27	1.33	Very Low	0.13	0.05	Low
28	1.47	Very Low	0.15	0.06	Low
29	1.71	Very Low	0.17	0.06	Low
33	1.82	Very Low	0.18	0.83	Low
40	48.36	Middle	4.84	1.83	Middle
41	153.33	Very Heavy	15.33	5.81	High
42	219.58	Very Heavy	21.96	8.32	High
43	1.22	Very Low	0.12	0.05	Low
45	55.93	Middle	5.59	2.12	Middle
47	242.47	Very Heavy	24.25	9.18	High
48	1.56	Very Low	0.16	0.06	Low
52	1.52	Very Low	0.15	0.06	Low

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