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Potential Drought of Agricultural Land Due to Soil Damage Based on Land Mapping Unit

Siti Maro'ah[1,✉], Mujiyo[1], Ongko Cahyono[1], Muhammad Rizky Romadhon[1], Viviana Irmawati[1], Nanda Mei Istiqomah[1]

[1] Department of Soil Science, Faculty of Agriculture, Universitas Sebelas Maret, Surakarta, INDONESIA.

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Corresponding Author:
✉ maroah23@staff.uns.ac.id
(Siti Maro'ah)

ABSTRACT

Sediment deposition in the upstream river areas can cause drought and disrupt agricultural activities. This study aims to analyze the potential for drought in the Keduang Sub-Watershed based on the Land Map Unit. The Keduang Sub-Watershed area has high potential for the development of agricultural land for food crops, but is not free from the potential for drought. The study was conducted using a soil survey method that was strengthened by soil sampling and laboratory analysis. Parameters for determining soil damage that causes the potential for land drought include soil physical properties, namely specific gravity, structure, soil color, porosity, permeability, slope, and soil type. The results showed that the potential for drought at the research location was still high. This is influenced by the level of soil damage that varies from low, medium to high. Land drought can be an obstacle to agricultural activities, and improper land management can worsen the situation. Conservative actions to overcome this problem include the addition of organic matter, crop rotation, application of soil cover or mulch, and processing agricultural land according to the contour direction. These activities are expected to overcome soil damage so that the potential for drought can be overcome.

1. INTRODUCTION

Erosion in the upstream regions significantly reduces a reservoir's storage capacity, and diminishing its efficiency in mitigating drought conditions (Auliyani & Wahyuningrum, 2020). The accumulation of sediment in reservoirs resulting from upstream erosion, leads to a gradual decrease in their available volume, which can critically impact their ability to supply water during water scarcity (Avicenna *et al*., 2015). This process undermines the reservoir effectivity and exacerbates the challenges faced by both local communities and the broader environment during drought events. Given the increasing frequency and severity of such conditions, the findings underscore the urgent necessity for implementing comprehensive and integrated land and water management strategies. These strategies should focus on sustainable practices to reduce soil erosion, enhance watershed management, and improve water conservation techniques. Such efforts are essential to ensure the long-term viability of water resources (Loganathan *et al*., 2019), safeguard ecological balance, and support the resilience of local communities in the face of growing environmental challenges. Therefore, effective management is pivotal in maintaining water availability and promoting sustainability in regions vulnerable to climate variability and land degradation (Azis *et al*., 2021).

Research by Hidayat *et al*. (2018) found that this region experiences a lack of water, primarily in June and August. From 2002 to 2003, the area underwent a severe drought, classified as "very dry" according to the Palmer drought index. Despite the relatively small window of drought conditions, the impact on agriculture and local livelihoods was significant, as water scarcity directly affects crop production and the availability of resources for the community. Such instances underline the importance of understanding the patterns of drought and its consequences in the region to better prepare for future challenges.

Land use in Wonogiri consists mainly of green open spaces, including forests, mixed agriculture, fields, and moors, which cover nearly 90% of the area (BPS, 2019). These land uses play a vital role in maintaining the region's ecological balance and contribute to water conservation efforts. The area has a large enough catchment area to theoretically allow for adequate water conservation, yet, in practice, there are still pockets within the District that experience water scarcity (Wardani & Kurniawati, 2014). This contradiction points to a mismatch between the potential of the land and its actual capacity to meet the water needs of the local population. The presence of drought and water scarcity, despite these natural assets, calls for more targeted and efficient management of the catchment areas to ensure the equitable distribution of water resources (Nugroho, 2012).

Given the potential for agricultural development in Wonogiri, particularly for food crops, the risk of drought poses a significant threat to the expansion of this sector. The area's ability to sustain agricultural growth is hindered by recurring droughts, which can disrupt crop production and threaten food security. The objective of this study is to analyze drought characteristics to provide information for choosing disaster mitigation strategies. The results of this study, by identifying risk areas and applying appropriate mitigation techniques, are useful to provide recommendations for future agricultural land use planning and measures for effective soil and water conservation actions.

2. METHODS

2.1. Research Area

Research was conducted in the Keduang Subwatershed located between 7°32′ - 8°15′ S and 110°41′ - 111°18′ N in Nguntoronadi District, Wonogiri Regency (Figure 1). Keduang Subwatershed is part of the Bengawan Solo Watershed flowing into the Gajah Mungkur Reservoir. The reservoir should provide sufficient irrigation for its command area, but is experiencing shallowing due to sediment entering from the upstream area. The Keduang Subwatershed is one of the most significant sediment contributors to the reservoir. This is the basis for this research in Wonogiri Regency, part of the Keduang Subwatershed.

The Nguntoronadi District is characterized by a diverse landscape, encompassing various non-study areas, such as water bodies and densely populated settlements (Rendrarpoetri *et al*., 2024). Despite this diversity, the district harbors regions with significant potential for soil degradation, posing considerable land and water management challenges. Notably, the entire District is underlain by a uniform soil type, primarily classified as Inceptisols, indicative of soils in the early stages of development and often prone to degradation. The soil damage potential (SDP) across the region is classified as high, suggesting that the area is susceptible to erosion, nutrient depletion, and other forms of soil deterioration, particularly under intensive land use and climatic stresses.

2.2. Research Materials

The materials used are thematic maps, namely rainfall maps, land use maps, slope maps, and soil type maps (Figure 2) of Nguntoronadi District. Such materials will help analyze potential drought due to SDP. The research was performed through soil survey completed with soil sampling and laboratory analysis. Several parameters was observed to determine the damage to the soil that caused the potential for land drought. The parameters included the physical properties of the soil in terms of bulk density, structure, color, porosity, permeability, slope, and type of soil (Kurnia *et al*., 2006). Drought can disrupt agricultural activities, and improper land management can aggravate the situation.

Potential soil degradation was evaluated and classified applying quantitative analysis methods that apply matching and scoring methodologies. The scoring analysis approach was applied to aggregate the cumulative score results as well as the value of each superimposed thematic map. The next stage was matching, which involves comparing measured degradation of soil data from the field to established standard criteria. Soil parameters are most closely related to the possibility of soil degradation. We also referred to it as the determinant coefficient of soil degradation, which was calculated from the correlation results from the test.

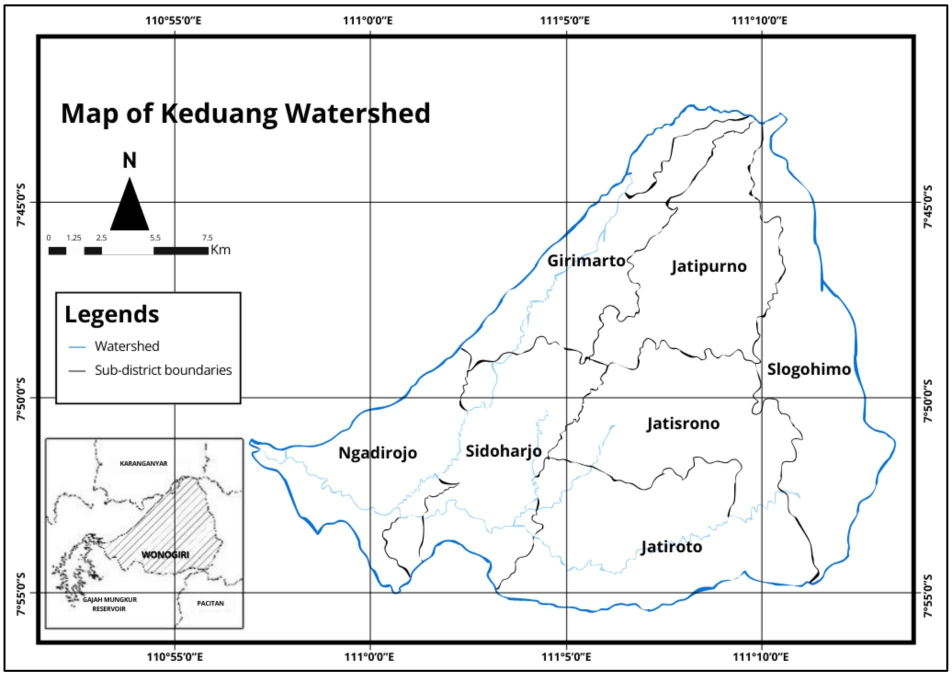
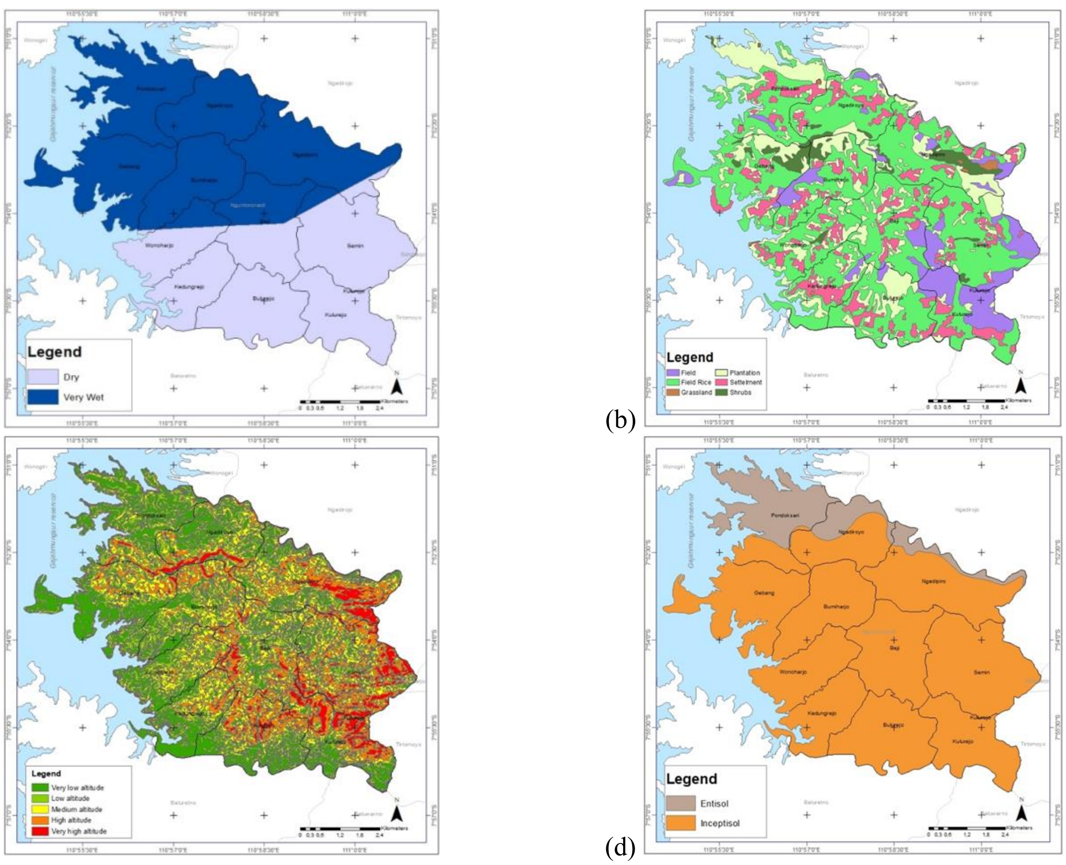


Figure 1. Map of Keduang Subwatershed



(a) (b) (c) (d)

Figure 2. Thematic maps of Nguntoronadi District: (a) Rainfall, (b) Land use, (c) Slope, and (d) Soil types

2.3. The SDP Analysis

The calculation of SDP analysis in this research was based on Geographic Information System (GIS) approach, which provides an effective way to assess and map the severity of drought across different regions. This method integrates several techniques, including scoring, weighting, and overlay, to produce a comprehensive analysis. Scoring was applied to various drought parameters, such as the vegetation index, rainfall, soil type, and land use, each of which plays a crucial role in determining the extent of drought conditions. The vegetation index helps assess plant health and moisture levels, while rainfall data provides insight into precipitation patterns. Soil type is considered to understand water retention capacity, and land use is incorporated to determine how human activity may impact the vulnerability to drought. By assigning appropriate weights to each parameter, the GIS system overlays the scored data layers to generate a detailed drought index, offering valuable insights into the spatial distribution and severity of drought in the study area. Scoring in this study is as follows:

$$SDP = \sum_{i=1}^{n} Wi \times Si^{n} \quad (1)$$

where *SDP* is soil damage potential, *Wi* is weighting index, *Si* is score index, and *n* is total indicators. The SDP classification was according to Table 2.

Table 1. The SDP from rainfall and soil properties

SDP Factors	Classification	Weight	Index	Weighting Index (Weight × Index)
Rainfall (mm/year)				
<1,000	Very low	3	1	3
1,000-2,000	Low	3	2	6
2,001-3,000	Moderate	3	3	9
3,001-4000	High	3	4	12
>4,000	Very high	3	5	15
Type of Land Use				
Endemic forest and paddy field	Very Low	2	1	2
Savana, shrubs, and mixed farm	Low	2	2	4
Farm and production forest	Moderate	2	3	6
Dryland	High	2	4	8
Open field	Very high	2	5	10
Land Slope (%)				
0-8	Very low	3	1	3
9-15	Low	3	2	6
16-25	Moderate	3	3	9
26-40	High	3	4	12
>40	Very high	3	5	15
Soil Types				
Vertisols	Very Low	2	1	2
Oxisols	Low	2	2	4
Alfisols, Mollisols, and Ultisols	Moderate	2	3	6
Entisols, Histosols, and Inceptisols	High	2	4	8
Andisols and Spodosol	Very high	2	5	10

Source: MNLH (2009)

Table 2. The SDP weighting index classification

Notation	Class	Weighting index
SDP 1	Very low	< 15
SDP 2	Low	15-24
SDP 3	Intermediate	25-34
SDP 4	High	35-44
SDP 5	Very high	> 45

Source: MNLH (2009)

3. RESULTS AND DISCUSSION

3.1. Land Use Type and Rainfall

Land use in Nguntoronadi District is predominantly focused on agricultural activities, with paddy fields and dryland cultivation occupying most of the landscape (Rahayu *et al.*, 2023). While essential for local livelihoods, this type of land use exacerbates the risk of soil erosion and degradation, especially when coupled with improper agricultural practices (Hossain *et al*., 2020). Furthermore, the District exhibits varied topography, with slopes ranging from 0% to 40%. These slopes are classified as moderate to high, which can further contribute to surface run-off, soil erosion, and other forms of land degradation, particularly during the rainy season.

The region experiences a relatively consistent rainfall pattern, with annual precipitation totaling approximately 2,250 mm. This moderate rainfall, while supporting agricultural activities, also presents challenges regarding soil conservation. When combined with the region's slope and soil characteristics, the volume of rains creates conditions conducive to water-induced erosion and sedimentation, particularly in areas with steep gradients or insufficient ground cover. Therefore, it is crucial to implement adequate soil and water conservation practices, including adopting sustainable agricultural techniques and improved land management strategies, to mitigate the potential for further soil degradation and ensure long-term agricultural productivity in the District.

3.2. The SDP Analysis

A guided theme map presents land characteristics to determine the potential for soil damage. Furthermore, scoring and interpretation were carried out using Arcview GIS in the form of a map of potential land damage in Nguntoronadi District. The data obtained from the study results were carried out through ANOVA analysis. The first stage to assess potential soil damage is to create a working map with components of a map of marbles, soil type, rainfall, and land use maps. With the map data, a Land Map Unit (LMU) is compiled (Figure 3), where the condition for obtaining an LMU is that it must have homogeneous components from the angle of marbles, soil type, rainfall, and land use. The creation of overlays and determination of sample points is done using ArcGIS 10.4 software.

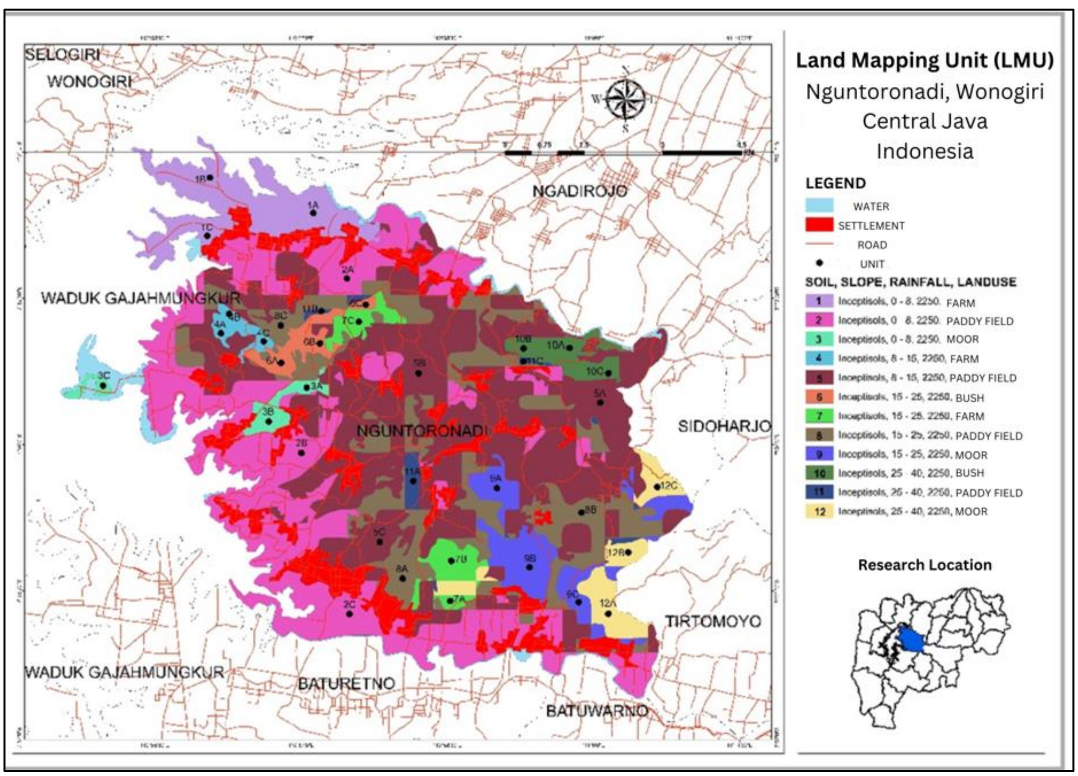


Figure 3. Land Mapping Unit (LMU) of Nguntoronadi District

There are 12 LMU with 3 replication, which means that 36 sample points were taken from the purchase object for later analysis and observation of the physical health of the soil. After obtaining the LMU, the next stage is assessing potential soil damage in Nguntoronadi District. It is carried out by evaluating the potential for soil damage by scoring a theme map and assessing the potential for soil damage in the field. Nguntoronadi District is one of the sub-districts in Wonogiri Regency, Central Java, which has the potential to develop agricultural land for food crops depending on the running of existing agricultural activities. In Table 3, we can see that land use dominates the research site are classified as having high SDP (4 LMUs) followed by low and intermediate SDP (2 LMUs for each). As will be seen later, however, LMU with low SDP dominates the Keduang Subwatershed in term of areas.

Table 3. The results of the analysis of soil physical properties in several land uses in Nguntoronadi District

LMU	BD	PS	PB	K	W	T	S	Class and Notation
1	2.11a	0.30ab	0.59ab	5.37e	2.00a	2.00b	1.33b	Very low (SDP 1)
2	2.07a	0.23b	0.03b	6.63e	4.00a	3.00ab	2.33ab	Low (SDP 2)
3	1.99ab	0.26ab	0.35ab	11.43cde	4.67a	2.67ab	2.67ab	Low (SDP 2)
4	1.92ab	0.24ab	1.00ab	23.40abc	2.00a	3.67ab	3.00a	High (SDP 4)
5	2.00ab	0.24ab	0.30ab	18.30bcde	4.33a	4.67a	3.00a	Intermediate (SDP 3)
6	1.95ab	0.25ab	0.23ab	16.67bcde	4.33a	3.00ab	2.33ab	Intermediate (SDP 3)
7	2.10a	0.27ab	0.32ab	22.33abcd	4.00a	4.33ab	3.00a	High (SDP 4)
8	1.87ab	0.25ab	0.26ab	8.33de	4.33a	4.00ab	3.33a	Low (SDP 2)
9	1.93ab	0.32a	0.03ab	28.50ab	4.00a	2.67ab	2.67ab	High (SDP 4)
10	1.70b	0.26ab	0.38ab	24.80abc	4.33a	3.00ab	2.67ab	High (SDP 4)
11	1.94ab	0.24ab	0.82ab	21.60abcd	4.00a	2.33ab	2.00ab	Intermediate (SDP 3)
12	1.89ab	0.27ab	1.90a	33.80a	4.33a	3ab	2.67ab	Very high (SDP 5)

Note: BD (bulk density), T (texture), S (structure), PB (permeability), K (slope), PS (porosity), W (color). Numbers followed by different notations indicate a statistically significant difference between data classes (sig. <0.05).

Table 4. Assessment of the highest values for soil physics parameter in several land uses

Soil Physics Parameter	LMU
Bulk density (BD)	7
Texture (T)	7
Structure (S)	4 & 5
Permeability (PB)	12
Slope (K)	12
Porosity (P)	9
Color (W)	3

The study results illustrated that Nguntoronadi District has a reasonably diverse average value or score from each parameter of soil physics properties (Table 4). The soil performance indicators are bulk density, texture, structure, color of the soil, porosity, permeability, slope, and soil type. Mapping soil damage potential (SDP) follows the procedures contained in government regulation No. 150/2000 (Presiden RI, 2000)and Regulation of the Minister of the Environment number 7/2006 (MNLH, 2006). A correlation test is necessary to determine the relationship between the soil's physical parameters. The results of the correlation test are presented in Table 5.

Table 5. Correlation of parameters

Correlation	BD	T	S	PB	PS
T	0.103				
S	0.107	**0.755****			
PB	0.097	-0.121	-0.030		
PS	-0.168	-0.099	0.064	-0.134	
K	0.283	0.043	-0.143	-0.127	-1.84

Throughout its operation, the Gajah Mungkur Reservoir experienced sedimentation of 3.1 million m^3 each year. An enormous sediment flow was contributed by the Keduang Subwatershed (Aisy *et al*., 2023). The erosion and sedimentation rate of the Keduang Subwatershed in the Pengkol Check Dam area of 6260 ha using the USLE method was 57,136 m^3/year. Estimation of sediment volume for 8 years using the Meyer – Peter Muller Equation of 320,065 m^3/year (Rahayu, 2016). This shows that erosion and sedimentation in the Wonogiri area, especially the Keduang Subwatershed, occurred in long time and continued.

The Keduang Subwatershed is one of the sub-watersheds contributing the largest sedimentation in the Gajah Mungkur Reservoir. In some regions, a water crisis will disrupt agricultural activities. Erosion and sedimentation resulting from uncontrolled soil damage. Damaged soil cannot perform its functions properly (Romadhon & Aziz, 2022). One of the soil functions is to store water reserves for use in agricultural activities, namely plant growth (Patra *et al*., 2022). The soil physics parameters that have been analyzed show that the potential for soil damage at the site is relatively high (Ebabu *et al*., 2022). This soil damage will encourage the potential for drought at the study site. Soil damage leads to erosion and sedimentation. As a result of erosion and excessive sedimentation, silting reservoirs cause reservoirs to be unable to hold water optimally (Morris, 2020).

Figure 4 shows that the majority of the Nguntoronadi District is made up of areas with high soil damage potential (SDP) of 192 ha (2.88%), moderate SDP of 1,647 ha (24.73%), and low SDP of 3,992 ha (59.94%). In the study area, the value of SDP at extremely low and very high potencies does not exist. The East to center and a small portion of the Southeast are regions with low to high SDP. The study site has the same type of soil, Inceptisols. Inceptisols are immature soils with a weaker profile development compared to mature soils and still have properties resembling the parent material's properties. Inceptisols are young soils and begin to develop (Hardjowigeno, 2003; Wulandari *et al*., 2021). The annual precipitation in Nguntoronadi region of 2,250 mm/year receives a rating of moderate SDP, and is not very diverse.

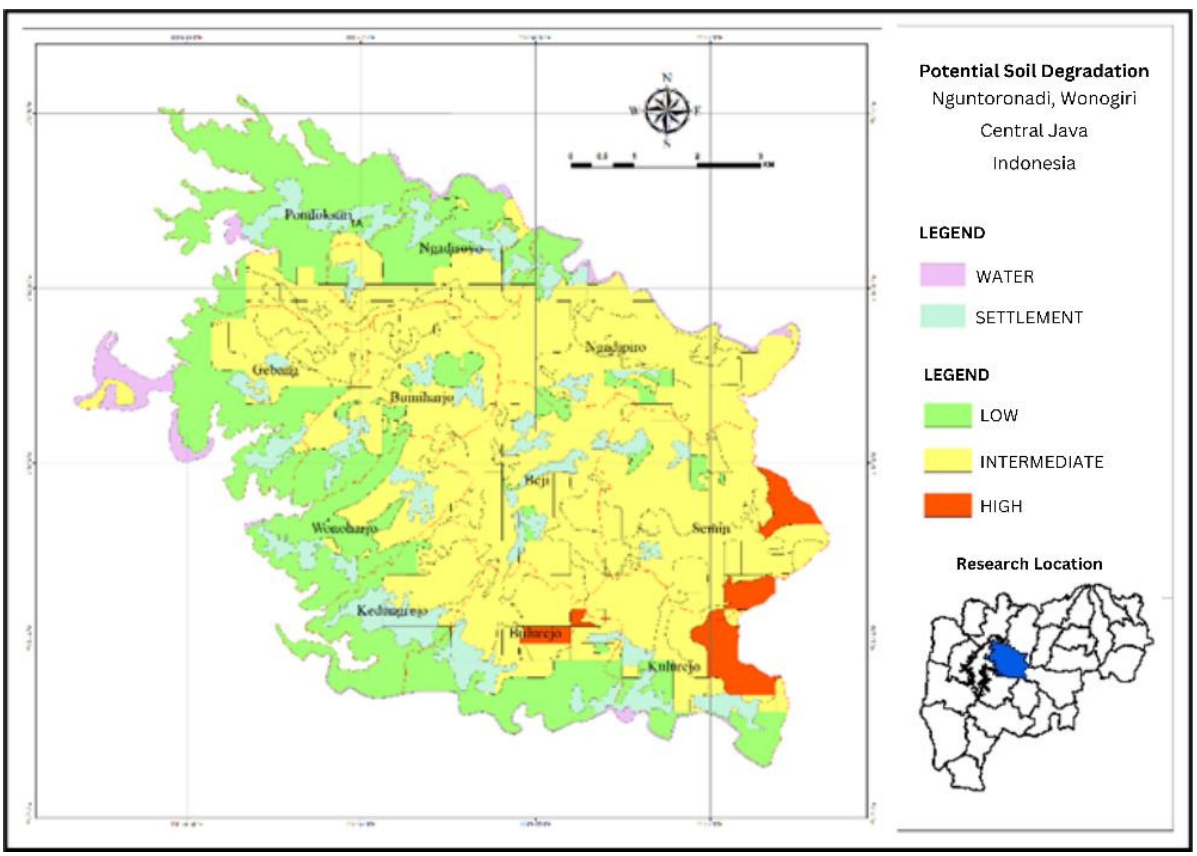


Figure 4. Map of potential land degradation in Nguntoronadi District

In Nguntoronadi, there is just one type of soil, the Inceptisols, with a grade of high SDP. This district has a slope at the site dominated by high slopes (Wiraatmaja *et al*., 2024). This has the potential to cause soil damage. Appropriate land use can minimize soil damage. In the location of the land, a lot of effort is cultivated for paddy fields and dryland, which are very prone to soil damage (McLeod *et al*., 2020). Intense dryland processing can drain nutrient content. The slope is high, and the plants cultivated in the dryland system are less able to prevent erosion and sedimentation. Rainwater will easily escape so that it cannot enter the soil as a water reserve for plants (Gürsu, 2024).

The analysis results of soil type, rainfall, slope, and land use show that the location is included in the area that is prone to soil damage. Damaged soil will not function properly, especially when capturing and storing water. This results in high erosion and sedimentation, so it can be said that the site has the potential for drought. Nguntoronadi District has a low land damage potential (SDP 2) of 3992 ha (59.94%), medium (SDP 3) of 1647 ha (24.73%), and high (SDP 4) of 192 ha (2.88%). Paddy field use dominates the study area with an area of 4489 ha, dominating all land use at around 67.40% compared to the second and third land uses, namely gardens of 583 ha (8.75%) and dryland of 553 ha (8.30%). Land use of paddy fields has a low potential for soil damage because it is carried out in areas with flat topography, and with the implementation of cultivation, farmers always apply land conservation practices. In contrast, on average, dryland has a moderate and most extensive potential for damage on a rather steep slope.

Soil physics parameters in this study were used to predict soil damage that occurred. Correlations between parameters were analyzed using a simple Bivariate correlation, which was used to determine the relationship between research variables. Thus, the relationship between each parameter can be known. The analysis results showed a very influential correlation, namely soil texture and structure, with a correlation value 0.755. This result can be interpreted if the correlation between the two parameters is robust, above 0.7. Soil texture and structure are essential physical properties. These two properties are closely related to soil particles and the condition of water and air in the soil. The management of texture and structure is considered from two sides, namely in terms of plant growth and soil preservation. The management of both can maintain good conditions such as porosity, aggregation, permeability, rooting of the plant, and other soil properties. The land is a natural resource and one of the media that can produce biomass (Knápek *et al*., 2020). Therefore, soil is an essential component supporting human life (Mujiyo *et al*., 2020). On the other hand, biomass production activities that are carried out continuously can reduce the ability of the soil to maintain its function as a biomass producer. Increased activity production that utilizes natural resources can cause land damage for biomass production activities, so the decline in soil quality and function can threaten the survival of human life (Wassie, 2020).

From the results of the analysis that has been carried out, it can be concluded that the potential for soil damage at the site is moderate to high. This can cause the location to have the potential to experience drought. In addition, it can also reduce soil damage, such as erosion and sedimentation. Proper management can increase infiltration and percolation capacity to minimize run-offs and erosion (Roy & Chowdhury, 2024). The movement of water in the soil is well regulated so that it can avoid soil destructive power (Hussain *et al*., 2022). Water entering the soil can be stored well and used for plant growth. Damaged textures and structures and improper management can result in soil damage (Scala *et al*., 2022). Water cannot enter and is appropriately stored in the soil so that surface flow occurs, which, if left unchecked, will cause erosion, which causes continuous soil damage. This situation causes the soil to lack water reserves, so there will be drought (Gavrilescu, 2021).

4. CONCLUSION

Wonogiri Regency is an area that still has the potential for drought. The Gajah Mungkur Reservoir, which should be able to provide sufficient irrigation for the site, has experienced silting due to sediment received from the upstream region. Upstream erosion has reduced reservoir volume. One of the most significant sediment contributors is the Keduang watershed. Soil damage is suspected to be the cause of the problem. The majority of the Nguntoronadi District is made up of areas with high soil damage potential (SDP) of 192 hectares (2.88%), moderate SDP of 1,647 hectares (24.73%), and low SDP of 3,992 hectares (59.94%). The results stated that the study site could experience drought due to soil damage. Significant locations are cultivated for productive land. Agricultural activities can be disrupted if the problem is not addressed, especially in the paddy field system. There needs to be conservative action to overcome the problem. Things that can be done include adding organic matter, crop rotation, applying ground covering materials or mulch, and working on agriculture according to the direction of the contours. These activities are expected to be able to overcome soil damage so that the potential for drought can be faced and minimized by the community. Further research is needed to see if the damage continues and the efforts to address the existing problems.

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REFERENCES

Aisy, R., Sukmono, A., & Firdaus, H.S. (2023). Analisis perubahan laju erosi pada Sub DAS Keduang tahun 2016 – 2021 dengan metode Universal Soil Loss Equation (USLE). *Jurnal Geodesi Undip*, 12(2), 111-120.

Auliyani, D., & Wahyuningrum, N. (2019). Sebaran potensi kekeringan meteorologis di Daerah Aliran Sungai Bengawan Solo bagian hulu dan upaya penanggulangannya. *Majalah Geografi Indonesia*, ***33***(2), 58-63. https://doi.org/10.22146/mgi.45534

Avicenna, A.K., Hadiani, R., & Solichin, S. (2015). Indeks kekeringan hidrologi di DAS Keduang berdasarkan metode Flow Duration Curve (FDC). *Matriks Teknik Sipil*, ***3***(3). Retrieved from https://jurnal.uns.ac.id/matriks/article/view/37283

Azis, A.A.A., Mujiyo, M., Cahyono, O. (2021). Mapping of soil degradation potential in Nguntoronadi District Wonogiri Regency. *IOP Conference Series: Earth and Environmental Science*, ***905***(1), 012085. https://doi.org/10.1088/1755-1315/905/1/012085

Badan Pusat Statistik [BPS]. (2019). *Kecamatan Nguntoronadi Dalam Angka 2019*. Wonogiri: BPS Kabupaten Wonogiri. Retrieved from https://wonogirikab.bps.go.id/id/publication/2019/09/26/729e99174d58d283f31578e2/kecamatan-nguntoronadi-dalam-angka-2019.html

Ebabu, K., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Adgo, E., Fenta, A.A., Meshesha, D.T., Berihun, M.L., Sultan, D., Vanmaercke, M., Panagos, P., Borrelli, P., Langendoen, E.J., & Poesen, J. (2022). Global analysis of cover management and support practice factors that control soil erosion and conservation. *International Soil and Water Conservation Research*, ***10***(2), 161–176. https://doi.org/10.1016/j.iswcr.2021.12.002

Gavrilescu, M. (2021). Water, soil, and plants interactions in a threatened environment. *Water*, ***13***(19), 2746. https://doi.org/10.3390/w13192746

Gürsu, H. (2024). An Affordable system solution for enhancing tree survival in dry environments. *Sustainability*, ***16***(14), 5994. https://doi.org/10.3390/su16145994

Hardjowigeno, S. (2003). *Klasifikasi Tanah dan Pedogenesis*. Jakarta: Akademika Pressindo.

Hidayat, A.M., Mulyo, A.P., Azani, A.A., Aofany, D., Nadiansyah, R., & Rejeki, H.A. (2018). Evaluasi ketersediaan sumber daya air berbasis metode neraca air Thornthwaite Mather untuk pendugaan surplus dan defisit air di Pulau Jawa. *Prosiding SNFA (Seminar Nasional Fisika dan Aplikasinya)*, ***3***, 35-46. https://doi.org/10.20961/prosidingsnfa.v3i0.28506

Hossain, A., Krupnik, T.J., Timsina, J., Mahboob, M.G., Chaki, A.K., Farooq, M., Bhatt, R., Fahad, S., & Hasanuzzaman, M. (2020). Environment, climate, plant and vegetation growth. In *Agricultural land degradation: Processes and problems undermining future food security* (pp. 17–61). Springer. https://doi.org/10.1007/978-3-030-49732-3_2

Hussain, A., Rehman, F., Rafeeq, H., Waqas, M., Asghar, A., Afsheen, N., Rahdar, A., Bilal, M., & Iqbal, H.M. (2022). In-situ, Ex-situ, and nano-remediation strategies to treat polluted soil, water, and air–A review. *Chemosphere*, ***289***, 133252. https://doi.org/10.1016/j.chemosphere.2021.133252

Knápek, J., Králík, T., Vávrová, K., & Weger, J. (2020). Dynamic biomass potential from agricultural land. *Renewable and Sustainable Energy Reviews*, ***134***, 110319. https://doi.org/10.1016/j.rser.2020.110319

Kurnia, U., Agus, F., & Aimihardja, A. (2006). *Sifat fisik tanah dan metode analisisnya*. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian (BBSDLP). https://repository.pertanian.go.id/handle/123456789/14955

Loganathan, G.B., Mohan, E., & Kumar, R.S. (2019). IoT based water and soil quality monitoring system. *International Journal of Mechanical Engineering and Technology (IJMET)*, ***10***(2), 537-541. Retrieved from https://eprints.tiu.edu.iq/698/

McLeod, M.K., Sufardi, S., & Harden, S. (2020). Soil fertility constraints and management to increase crop yields in the dryland farming systems of Aceh, Indonesia. *Soil Research*, ***59***(1), 68-82. https://doi.org/10.1071/SR19324

MNLH (Menteri Negara Lingkungan Hidup). (2006). *Peraturan Menteri Negara Lingkungan Hidup Nomor 07 Tahun 2006 tentang Tata Cara Pengukuran Kriteria Baku Kerusakan Tanah Untuk Produksi Biomassa*. Direktorat Jenderal Kementerian Lingkungan Hidup dan Kehutanan, Jakarta.

MNLH (Menteri Negara Lingkungan Hidup). (2009). *Peraturan Menteri Negara Lingkungan Hidup Nomor 17 Tahun 2009 tentang Pedoman Penentuan Daya Dukung Lingkungan Hidup dalam Penataan Ruang Wilayah*. Direktorat Jenderal Kementerian Lingkungan Hidup dan Kehutanan, Jakarta.

Morris, G.L. (2020). Classification of management alternatives to combat reservoir sedimentation. *Water,* ***12***(3), 861. https://doi.org/10.3390/w12030861

Mujiyo, M., Rahayu, R., & Sutopo, N.R. (2020). Implementasi evaluasi lahan untuk pengembangan komoditas tanaman berdasarkan kesesuaian agroklimat. *AgriHealth: Journal of Agri-Food, Nutrition and Public Health*, ***1***(2), 62-70. https://doi.org/10.20961/agrihealth.v1i2.44239

Nugroho, A.P. (2012). Analisis kekeringan Daerah Aliran Sungai Keduang dengan menggunakan metode Palmer. [*Undergraduated Thesis*]. Universitas Sebelas Maret.

Patra, S.K., Poddar, R., Brestic, M., Acharjee, P.U., Bhattacharya, P., Sengupta, S., Pal, P., Bam, N., Biswas, B., Barek, V., Ondrisik, P., Skalicky, M., & Hossain, A. (2022). Prospects of hydrogels in agriculture for enhancing crop and water productivity under water deficit condition. *International Journal of Polymer Science*, ***2022***, 4914836. https://doi.org/10.1155/2022/4914836

Presiden RI (Republik Indonesia). (2000). *Peraturan Pemerintah Republik Indonesia Nomor 150 Tahun 2000 tentang Pengendalian Kerusakan Tanah untuk Produksi Biomassa*. Lembaran Negara Tahun 2000 Nomor 267, Tambahan Lembaran Negara Nomor 4068.

Rahayu, E.S., Widadie, F., & Setyowati. (2023). Performance of environmentally sound cassava farming as an effort to increase income after covid 19 in the Bengawan Solo Wonogiri Watershed. *IOP Conference Series: Earth and Environmental Science*, ***1180***(1), 012007. https://doi.org/10.1088/1755-1315/1180/1/012007

Rahayu, T. (2016). Evaluasi fungsi bangunan pengendali sedimen (*Check DAM*) Pengkol berdasarkan tata guna lahan Kali Keduang Kabupaten Wonogiri. [*Undergraduated Thesis*]. Universitas Sebelas Maret.

Rendrarpoetri, B.L., Rustadi, E., Fauzi, A., & Pravitasari, A.E. (2024). Local sustainability assessment of the wonogiri multipurpose reservoir catchment area in Central Java Province, Indonesia. *Land*, ***13***(11), 1938. https://doi.org/10.3390/land13111938

Romadhon, M.R., & Aziz, A. (2022). Determination of flood susceptibility index using overlay-scoring data method based on geographic information system (GIS) in Semarang city, Central Java, Indonesia. *AgriHealth: Journal of Agri-food, Nutrition and Public Health*, ***3***(2), 104-123. https://doi.org/10.20961/agrihealth.v3i2.60451

Roy, S.K., & Chowdhury, M.A. (2024). Morphometric analysis and watershed delineation of the Karnaphuli river basin: A comparative study using different DEMs in Chittagong, Bangladesh. *River*, ***3***, 426–437. https://doi.org/10.1002/rvr2.109

Scala, S.A., Gaudio, C.D., & Verderame, G.M. (2022). Influence of construction age on seismic vulnerability of masonry buildings damaged after 2009 L'Aquila earthquake. *Soil Dynamics and Earthquake Engineering*, ***157***, 107199. https://doi.org/10.1016/j.soildyn.2022.107199

Wardani, H.K., & Kurniawati, W. (2014). Kajian desain kawasan berbasis konsep WSUD (Water Sesitive Urban Design) di daerah langka air (Studi kasus: Desa Gambirmanis, Kec. Pracimantoro, Kab. Wonogiri). *Ruang*, ***2***(3), 221-230. Retrieved from https://ejournal3.undip.ac.id/index.php/ruang/article/view/5683

Wassie, S.B. (2020). Natural resource degradation tendencies in Ethiopia: A review. *Environmental systems research*, ***9***(1), 1-29. https://doi.org/10.1186/s40068-020-00194-1

Wiraatmaja, M.F., Kusumaningrum, L., Herdiansyah, G., Mujiyo, M., Anggita, A., Romadhon, M.R., & Irmawati, V. (2024). Flood vulnerability assessment trough overlay-scoring data method based on Geographical Information System (GIS) in Giriwoyo, Wonogiri, Indonesia. *IOP Conference Series: Earth and Environmental Science*, ***1314***(1), 012109. https://doi.org/10.1088/1755-1315/1314/1/012109

Wulandari, A., Lopulisa, C., & Ahmad, A. (2021). Analysis of soil characteristics and classification from order to family category in Makale District. *IOP Conference Series: Earth and Environmental Science*, ***807***(4), 042006. https://doi.org/10.1088/1755-1315/807/4/042006