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Research

Identification of criticalwatershed pakerisan based on remote sensing and geographic information systems for sustainable land capability

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Abstract
Watersheds can be viewed as natural systems where complex hydrological biophysical processes as well as socio-economic and cultural activities of the community take place. Changes in watershed hydrological conditions as a result of uncontrolled expansion of cultivation areas without regard to soil and water conservation principles often lead to conditions of increased erosion and sedimentation, decreased land productivity, and accelerated land degradation. The purpose of this research was to determine the level of erosion's danger and critical level of land in the watershed Pakerisan. Determination of the critical level of land is done by evaluating the parameter determining critical areas, such as the closure and land productivity, slope, erosion, and land management with the scoring method. The level of erosion's danger is calculated using the Universal Soil Loss Equation (USLE). The results shows that the level of the erosion's danger in the watershed Pakerisan is very light of 38 covering 4654.69 ha (51.19%), light as many as 44 units of land area of 3243.54 (35.68%), medium 15 units of land area of 1022.29 ha (11.24%) and weight 3 units of land area of 171.97 ha (1.89%). Critical level of land area in Watershed Pakerisan consists of a non-critical area of 5653.99 ha (62.19%), potential critical area of 1951.67 ha (21.47%) and rather critical area of 1486.23 ha (16.35%). Avoid further escalation of the critical level of land in the watershed Pakerisan, the real efforts of stakeholders including government, private, and community is needed
Keywords: critical; pakerisan; sustainable land capability; watershed

1. Introduction

Pakerisan watershed is one area that has been designated by UNESCO as a World Cultural Heritage. Pakerisan watershed is a watershed districts that are mostly located in Bangli upstream and downstream in Gianyar. The changes in upstream may threaten the hydrological functions downstream to upstream management (Asdak, 2010; Effendi, 2013). To maintain the hydrological functions, it is needed an integrated and sustainable management system so that the occurrence of critical land can be avoided (Suyanto, 2007). One indicator is the existence of critical land erosion that can affect the productivity of land, which usually occurs in the upper reaches of the watershed, which

generally have steeper slopes (Arsyad, 2010). This could have a negative impact on the downstream part of the river basin sedimentation in the estuary. In addition, if there is no integrated and sustainable management, it will threaten the sustainability of the Pakerisan watershed. Consequently, resolution as a World Cultural Heritage of UNESCO will be reviewed or even repealed(Syam, 2003).

Mapping of critical land in the Pakerisan watershed is needed to provide appropriate management level. The rapid development of technology in the field of remote sensing and Geographic Information Systems are combined to be very useful in providing the desired spatial information (Pratiwi, 2012). It is to make the process easier. With facilities and advantages provided by combination of Geographic Information System which supported the development of cutting-edge technology in the field of remote sensing will assist the mapping of critical lands in the Pakerisan watershed. This study aims at determining the level of erosion and land critical level in every function area in the Pakerisan watershed.

2. Methods

This research was conducted in the Pakerisan watershed. It is located between 8 ° 16'46,579 " - 8 ° 36'50,012 " latitude and 115 ° 17'50,051 " - 115 ° 21'53,445 " BT. Administratively, Pakerisan watershed is located in Bangli and Gianyar district with an area of 9091.89 ha . (Figure 1).

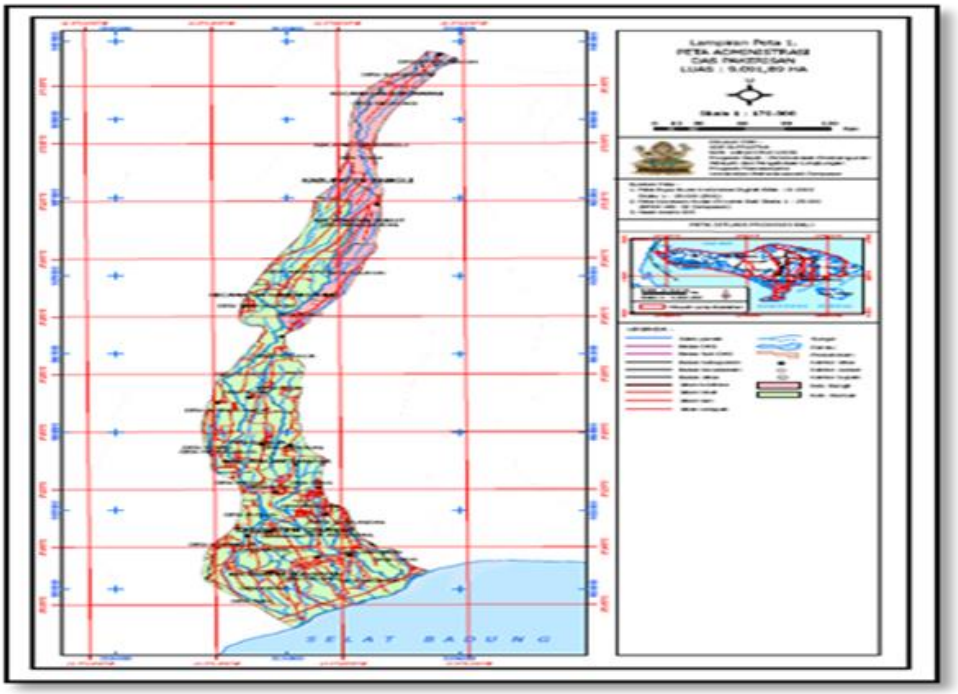


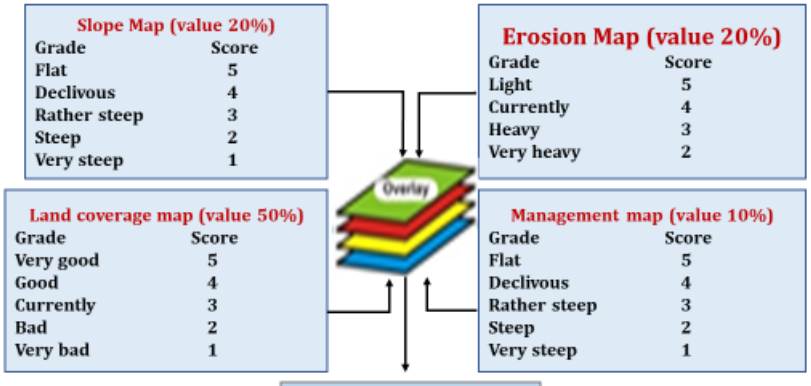
Figure 1. Map of Pakerisan watershed

Research Tools used are GPS, digital cameras, stationery, and a set of computers that come with ArcGIS software version 10.1. The materials used in this study were; rainfall data from 2005 to 2014 in the last 10 years in the research area, maps Thematic research sites that relate to the research objectives as: Map Erodibility Land and Soil Depth, Map RBI (RBI), Map Slope Land, Map Shape Land, Map function Zone, and Land Cover Map. C. Procedure Research The procedure of this study begins to interpret Landsat imagery (Landsat 8), followed by making a map Pakerisan Watershed Unit which is based on maps of topography, geomorphology maps (landforms), Pakerisan watershed land cover

maps and administrative maps. Field surveys conducted to obtain primary data on the location of the research such as data of vegetation cover and land management.

Data analysis was performed on each function of the area in the basin Pakerisan. Basically the analysis conducted is overlaying (overlay) of a parameter determining the degree of criticality of land. Flowchart Determining Criticality Level 1 Land as shown in image.

From the diagram below can be explained that the critical level of land is a total score of multiplication score with the weight of each parameter. Scores and weights of each function of the area are as follows.



Land criticality level	Protected forest area Total score	Agricultural cultivation area (total score)	Protected area outside the forest area (Total score)
Very critical	120-180	115-200	110-200
Critical	181-270	201-275	201-275
Rather critical	271-360	276-350	276-350
Potential critical	361-450	351-425	351-425
Not critical	451-500	426-500	426500

Figure 2. Flowchart of Determining the Critical Level of Land

Scores and weights of each of the Critical parameters of land in protected forest areas shows as Table 1

Table 1 . Criteria for Critical Areas Protected Forest Areas

No	Criteria (% weight)	Class	Quantity/ Description	Score	Description
1	Land cover (50)	Excellent	>80%	5	Assessed based on the percentage of tree cover
		Good	61-80 %	4	
		Medium	41-60 %	3	
		Poor	21-40 %	2	
		Very Poor	<20 %	1	
2	Slope (20)	Flat	<8 %	5	
		Rather Plat	8 -15 %	4	
		Rather Steep	16-25 %	3	
		Steep	26-40 %	2	
		Vary Steep	>40 %	1	
3	Erosion (20)	1. Lightweight	0 dan I	5	calculated using USLE formulas
		2. Medium	II	4	
		3. weight	III	3	
		4. Very Serious	IV	2	

No	Criteria (% weight)	Class	Quantity/ Description	Score	Description
4	Management (10)	1. Good 2. Medium 3. Poor	Complete *) Incomplete There is no	5 3 1	*) Existing area of boundary - There is a security / surveillance - Extension implemented

Source: Ministry of Forestry, 2013

Scores and weights of each of the Critical parameters of land on the areas of agricultural cultivation as Table 2.

Table 2. Criteria for Critical Areas Agriculture

No	Criteria (% weight)	Class	Quantity/ Description	Scor	Description
1	Productivity *) (30)	1. Excellent 2. Good 3. Medium 4. Poor 5. Very Poor	>80% 61-80 % 41-60 % 21-40 % <20 %	5 4 3 2 1	*) Based on the ratio of the general commodity optimal production on traditional management
2	Slope (20)	1. Flat 2.Rather Plat 3.Rather Steep 4.Steep 5. Vary Steep	<8 % 8 -15 % 16-25 % 26-40 % >40 %	5 4 3 2 1	
3	Erosion (20)	1. Lightweight 2. Medium 3. weight 4. Very Serious	0 dan I II III IV	5 4 3 2	calculated using USLE formulas
4	Management (30)	1. Good 2. Medium 3. Bad		5 3 1	Full application of soil conservation technologies and corresponding technical instructions Incomplete or not maintained There is no

Source: Ministry of Forestry, 2013

Scores and weights of each of the Critical parameters critical level of land in the area of protected areas outside forest area is as the Table 3.

Table 3. Crireia of critical areas of pretected land outside forest

No	Criteria (% weight)	Class	Quantity/ Description	Skor	Keterangan
1	Permanent Vegetation (50)	1. Excellent 2. Good 3. Medium 4. Poor 5. Very Poor	>40% 31-40 % 21-30 % 10-20 % <10 %	5 4 3 2 1	

No	Criteria (% weight)	Class	Quantity/ Description	Skor	Keterangan
2	Slope (20)	Flat	<8 %	5	
		Rather Plat	8 -15 %	4	
		Rather Steep	16-25 %	3	
		Steep	26-40 %	2	
		Vary Steep	>40 %	1	
3	Erosion (20)	1. Lightweight	0 dan I	5	calculated using USLE formulas
		2. Medium	II	4	
		3. weight	III	3	
		4. Very Serious	IV	2	
4	Management (30)	Good		5	Full application of soil conservation technologies and corresponding technical instructions
		Medium		3	Incomplete or not maintained
		Poor		1	There is no

Source: Ministry of Forestry, 2013

The sum score is further classified to determine the level of critical land. Classification level of critical land based on the total score of critical land parameters is shown in Table 4.

Table 4. Criticality Level Land Classification Based on Total Score

Total Score On:			Criticality Level og Land
Protected Forest Areas	Agriculture Zone	Protected areas outside the forest area	
120 – 180	115 - 200	110 - 200	Highly critical
181 – 270	201 - 275	201 - 275	Critical
271 – 360	276 - 350	276 - 350	Rather critical
361 – 450	351 - 425	351 - 425	Potential critical
451 – 500	426 - 500	426 - 500	Not critical

Source: Ministry of Forestry, 2013

Based on the description, the parameters must be subjected to analysis to which it is the rate of erosion (TBE). To predict the erosion equation in accordance with the formula Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978), it is used the following equation:

$A = R\ K\ LS\ C\ P$

Where :
A = Number of lost soil (ton ha^{-1} yr^{-1})
R = Index rain erosivitas

K = soil erodibility index
LS = length of index and slope
C = Index crop management
P = index soil conservation efforts

Class and rate of erosion (TBE) is calculated based on the Decree of the Director General of Reforestation and Land Rehabilitation, Ministry of Forestry No. 041 / Kpts / V / 1998 dated 21st April 1998 by comparing the rate of erosion in an area of land (land units) with soil depth effective on unit the land. Class and rate of erosion can be obtained using a simple matrix, as presented in Table 5.

Table 5. Solum combination Soil and Erosion in TBE Determination

The depth of the soil (cm)	Erosion class				
	I	II	III	IV	V
	Erosion (ton ha^{-1} $year^{-1}$)				
	<15	15-60	60-180	180-480	>480
Depth	SR	R	S	B	SB
>90	0	I	II	III	IV
Medium	R	S	B	SB	SB
60 – 90	I	II	III	IV	IV
Shallow	S	B	SB	SB	SB
30 – 60	II	III	IV	IV	IV
Very shallow	B	SB	SB	SB	SB
<30	III	IV	IV	IV	IV

Source : Departement of Forestry, 1998
Notes : 0-SR : Very light, I-R : Light, II-S : Medium, III-B : Weight, IV-SB : Very weight

3. Results and Discussion

Biophysical of Pakerisan watershed in this study, described the condition of administrative watershed distribution, annual rainfall, types of land cover, land slope, land form, erosion rate and land criticality level. Pakerisan Watershed has a total area of 9,091.89 hectares which is administratively located in 2 (two) districts, namely: Bangli Regency covering an area of 1,851.83 hectares (20.37%) and Gianyar covering an area of 7,240.06 hectares (79.63%). Bangli Regency consists of 2 (two) sub-districts, namely Kintamani District with an area of 561.00 hectares and Susut with an area of 1,290.83 hectares. Meanwhile, Gianyar Regency consists of 3 (three) sub-districts, namely Blahbatuh District with an area of 2,493.46 hectares, Gianyar with an area of 2,801.62 hectares and Tampaksiring with an area of 1,944.98 hectares.

The average annual rainfall for 10 years in Kintamani District is 2,003 mm $year^{-1}$ with 89 rainy days. The lowest rainfall occurred in August of 3 mm $month^{-1}$ with 1 rainy day and the highest was in January of 341 mm $month^{-1}$ with 14 rainy days.

Annual average rainfall for 10 years in the District of Tampaksiring is 2,644 mm $year^{-1}$ with 123 rainy days. The lowest rainfall occurred in June of 107 mm $month^{-1}$ with 9 rainy days and the highest occurred in December of 322 mm month-1 with 14 rainy days.

Annual average rainfall for 10 years in Gianyar District is 2,132 mm $year^{-1}$ with 103 rainy days. The lowest rainfall occurred in September of 66 mm $month^{-1}$ with 4 rainy days and the highest occurred in December of 283 mm $month^{-1}$ with 14 rainy days.

The amount of rainfall, intensity and distribution of rain determines the dispersion of rain on the soil, the amount and strength of surface runoff and the level of erosion damage (Arsyad, 2010). Based on rainfall data, according to Schmidt Ferguson, the climate type is C-D (slightly wet-moderate). Climate type C is located in the upstream of the Pakerisan

watershed, while climate type D is located in the downstream part of the Pakerisan watershed. With such conditions, the Pakerisan watershed area is suitable for agricultural cultivation.

Based on the interpretation of Landsat 8 and survey, land cover in the Pakerisan watershed consist of the permanent vegetation of 32.58 ha (0.36%), mixed garden area of 3,405.32 ha (37.45%), rice fields covering 4,592.00 (50.51%) and the residential area of 1061.99 (11, 68%) of the total watershed (Table 6).

Table 6.Types and Areas of Land Cover in the Pakerisan Watershed

No	Land Cover Types	Area (Ha)	%
1	2	3	4
1	Fixed Vegetation	32.58	0.36
2	Mixed Garden	3,405.32	37.45
3	Ricefield	4,592.00	50.51
4	Settlement	1,061.99	11.68
total		9,091.89	100.00

Source: Interpretation of Landsat imagery results

The type of vegetation cover on forest land use is dominated by shrubs, pine (*Pinus merkusii*), Ampupu (*Eucalyptus urophylla*), Kaliandra (*Calliandra haematocephala*) and elephant grass (*Penisetum purpureum*). Vegetation types in mixed garden land use are dominated by woody plants, estate crops, multipurpose plants and annual crops. Types of woody plants consist of Sengon *(Albizia chinensis*), Kejimas (*Duabanga mollucana*), Jabon (*Anthocephalus cadamba)* and Mahogany (*Swietenia mahagoni*). Types of plantation crops consist of Coffee (*Canthium dicoccum*), Chocolate (*Theobroma cacao*) and Oranges (*Citrus auranticum*) While the types of multipurpose plants consist of Durian (*Durio zibethinus*), Jackfruit (*Artocarpus heterophyllus*) and Avocado (*Persea americana*).For seasonal crops are dominated by salak, tubers and nuts. Meanwhile, land management measures include making traditional terraces. Vegetation cover on residential land use is dominated by annual plants in the form of kenikir flowers and agricultural crops (vegetable types) while soil conservation efforts are carried out in the form of traditional terraces. As for the cover of vegetation on the use of paddy fields consisting of rice.

The slope of the land in the Pekerisan watershed sequentially is flat with an area of 7,953.23 hectares (87.48%), sloping with an area of 966.69 hectares (10.63%) and rather steep with an area of 171.97 hectares (1.89%). The slope of the slope has a very large influence on the occurrence of erosion, the steeper the slope, the greater the water carrying energy so that erosion becomes greater (Arsyad, 2010). Based on the origin of the land forms that can be found in the Pakerisan watershed, these include landforms of volcanic origin with an area of 7,026.1 hectares (77.28%) and fluvial with an area of 2,065.79 hectares (22.72%).

Analysis of the predicted erosion in the watershed area Pakerisan, shows erosion in the Pakerisan watershed amounted to 276,685.26 tons year^{-1} or 4119.45 tons ha^{-1} yr^{-1}. The amount of erosion that occurs subsequently used to determine the grade of erosion and the rate of erosion in the watershed area Pakerisan. Class erosion in the Pakerisan watershed varies from class I to class IV. Area per each class of erosion from level I to class IV in sequence is first class area of 4654.09 hectares, or 51.19%, the erosion of class II, covering an area of 3243.54 hectares, or 35.68%, the erosion of class III area of 1,022, 29 hectares or 11.24% and grade IV erosion area of 171.97 hectares or 1.89% (Figur 3).

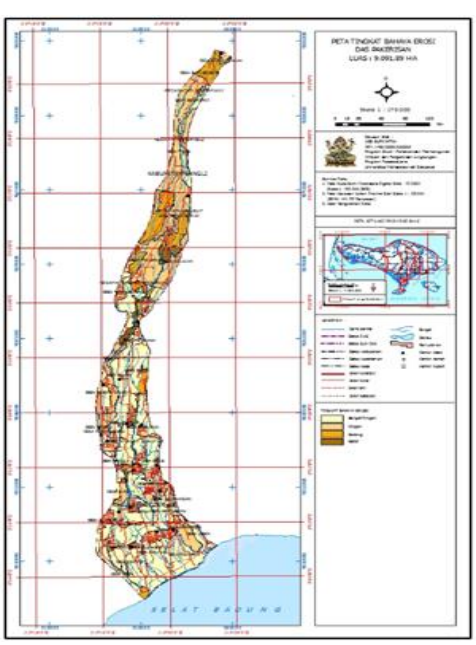
The level of erosion hazard is obtained by comparing the amount of erosion (actual erosion) with an effective depth of soil on the unit of land in the area concerned. The results

of erosion danger level analysis in the Pakerisan watershed varies from very light levels up to the level of severe and there are no lands that have high levels of erosion is very heavy. The level of erosion hazard successively presented as follows: very light level covering an area of 4654.09 hectares, or 51.19%, mild covering an area of 3243.54 hectares, or 35.68%, moderate covering an area of 1022.29 hectares, or 11.24%, and the weight covering an area of 171.97 hectares or 1.89%.

Referring to map the depth of soil, Pakerisan watershed area only has added to the land of> 90 cm. Using the criteria used by Thomson 1957 in (Arsyad, 2010) then theoretically erosion allowed to the ground with a depth> 90 cm with a bottom layer of high permeability above the substrate that has been decaying was 2.5 mm year- 1 or 30 ton ha^{-1} $year^{-1}$.

The amount of actual erosion that occurred in Pakerisan watershed has exceeded the tolerable erosion. It is sending a message that the vegetation cover, cropping and soil conservation measures that exist in the region have not been able to prevent the occurrence of erosion to a level that is not harmful (Widayani, 2015; Restu, 2014). That if left unchecked would adversely affect the watershed land Pakerisan which could result in unproductive or degraded land where erosion as one indicator. The conditions of necessary rescue efforts on Pakerisan watershed land.

Overall the critical level of land in the Pakerisan watershed is 5,653.99 ha (62.19%) non-critical, 1,951.67 ha (21.47%) critical potential and 1,486.23 ha (16.35%) somewhat critical . The distribution and critical level of land per area function classification direction and per village area in the Pakerisan watershed are presented Figure 4.



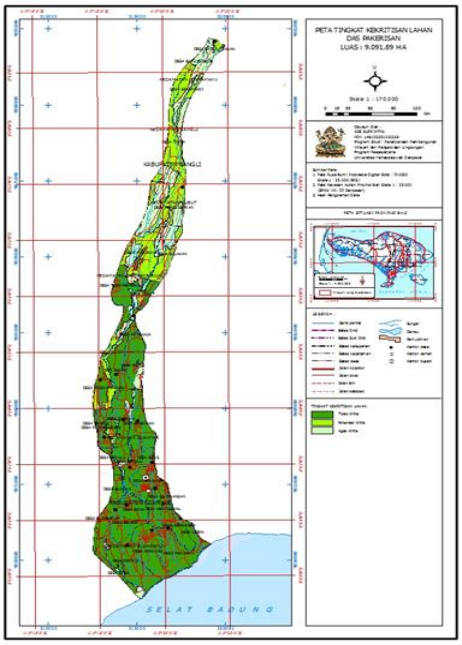


Figure 3. Erosion distribution of Pekerisan watershed (left)
Figure 4. Distribution of critical land in the Pekerisan watershed (right)

The results of this study indicate that although the dominant land area is not critical, namely 5,653.99 ha (68.42%), there is also a potentially critical land area of 1,951.67 ha (19.51%) and 1,486 rather critical land area. 23 ha (12.07%). The rather critical and potentially critical lands are scattered in the upstream and middle parts of the Pakerisan Watershed, if this rather critical and critical potential land is not handled properly it can turn into critical or very critical land. This needs to get priority handling, both by the

government, the private sector, and the community considering that the Pakerisan Watershed has a very strategic role and function, namely the conservation function, where the Pakerisan Watershed is also a watershed that has been designated by UNESCO as a world cultural heritage, where critical land upstream and/or in the middle can threaten the existence of hydrological functions needed by the community**.**

In order to prevent a change in the status of potentially critical land to moderately critical land, this needs to be addressed immediately. Efforts to handle rather critical and potentially critical land in the Pakerisan Watershed, are carried out by looking at all the factors that cause this critical land to occur.

For land cover factors in protected areas outside forest areas, efforts that can be made are sparse land cover through planting grass/grass strips, mixed cropping, planting according to contours, strips and alleys, agroforestry, while on medium land cover through plant enrichment activities and land use under stands.

Factors of land productivity in cultivation areas, efforts that can be made are increasing land productivity through the development of superior commodities, the use of superior varieties, the use of organic and inorganic fertilizers, agricultural intensification, and intercropping.

Management factors in protected forest areas, efforts that can be made, namely the reconstruction and mapping of forest area boundaries on a regular basis, routine security and monitoring patrols of forest areas, addition of personnel for security and supervision of forest areas *(jagawana*), involving village officials, both official and village villages customs in securing forest areas and continuous counseling by relevant agencies.

Management factors in protected areas outside forest areas and cultivation areas, efforts that can be made are through mechanical soil conservation in the form of: making mound.

4. Conclusions

Based on the results of research and discussion, it can be concluded:

1. The level of erosion hazard that occurs in the Pakerisan Watershed is very light level of 38 areas covering 4,654.69 ha (51.19%), a mild level of 44 units of land covering an area of 3,243.54 (35.68%), a medium level of 15 units of land area 1,022.29 ha (11.24%) and a weight level of 3 units of land covering an area of 171.97 ha (1.89%).
2. The criticality level of the land consists of 5,653.99 ha (62.19 %) not critical, 1,951.67 ha (21.47 %) critical potential and 1,486.23 ha (16.47 %) rather critical (35 %). The entire protected forest area of 32.58 ha is a critical potential. The protected area outside the forest area covers an area of 795.78 ha, consisting of a slightly critical area of 488.55 ha (61.39%) and a potential critical area of 307.23 ha (38.61%). The agricultural cultivation area in the Pakerisan watershed area consists of 87 land units covering an area of 8,263.53 ha consisting of slightly critical area of 997.68 ha (12.07%), critical potential area of 1,611.86 ha (19.51%) and non-critical area of 55,653, 99 ha (68.42%).

   Reducing the rate of erosion, on land with a high level of erosion hazard, it is necessary to change crop management and land management through soil conservation using vegetative and mechanical methods. While the index of rain erosivity, soil erodibility, and slope are parameters that are relatively difficult to change.

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References

Arsyad, S. 2010. Konservasi Tanah & Air. Edisi Kedua. Bogor : IPB Press. https://repository.ipb.ac.id/handle/123456789/42667

Asdak, C. 2010. Hidrologi Dan Pengelolaan Daerah Aliran Sungai. Edisi kelima. Yogyakarta : Gadjah Mada University Press. https://opac.perpusnas.go.id/DetailOpac.aspx?id=542343

Balai Pengelolaan DAS Unda Anyar, 2013. Rencana Teknik Rehabilitasi Hutan dan Lahan Daerah Aliran Sungai (RTk-RHL DAS) Wilayah Kerja BPDAS Unda Anyar. Denpasar: Balai Pengelolaan Daerah Aliran Sungai Unda Anyar. https://jdih.menlhk.go.id/new2/uploads/files/2022pmlhk14_menlhk_08082022112114.pdf

Departemen Kehutanan. 1998. Keputusan Direktur Jenderal Reboisasi dan Rehabilitasi Lahan Departemen Kehutanan Nomor: 041/Kpts/V/1998 tentang Pedoman Penyusunan Rencana Teknik Lapangan Rehabilitasi lahan dan Konservasi Tanah Daerah Aliran Sungai. Jakarta: Departemen Kehutanan RI. https://jdih.menlhk.go.id/new2/uploads/files/2022pmlhk010_menlhk_08022022151842.pdf

Departemen Kehutanan. 2001. Keputusan Menteri Kehutanan No:52/Kpts-II/2001 tentang Pedoman Penyelenggaraan Pengelolaan Daerah Aliran Sungai. Jakarta: Departemen Kehutanan RI. https://www.regulasip.id/book/5231/read

Departemen Kehutanan. 2009. Peraturan Menteri Kehutanan RI No:P. 39/Menhut-II/2009 Tentang Pedoman Penyusunan Rencana Pengelolaan Daerah Aliran Sungai Terpadu. Jakarta: Departemen Kehutanan RI. https://www.dsdan.go.id/?mdocs-file=2527

Departemen Pertanian. 1980. Keputusan Menteri Pertanian Nomor: 837/Kpts/Um/11/1980 tentang Kriteria dan Tata Cara penetapan Hutan Lindung. (cited 2013 Des.20).Available from : http://www.docstoc.com/docs/20556251

Departemen Pertanian. 1981. Keputusan Menteri Pertanian No 683/Kpts/Um/8/1981 tentang Kriteria dan Tata Cara Penetapan Hutan Produksi. (cited 2013 Des.20). Available from : http://www.docstoc.com/docs/2055625

Effendi, H. 2003. Telaah Kualitas Air bagi Pengelolaan Sumber Daya dan Lingkungan Perairan. Yogyakarta: Kanisius. https://opac.perpusnas.go.id/DetailOpac.aspx?id=495078

Kementerian Kehutanan. 2013. Peraturan Direktur Jenderal Bina Pengelolaan DAS dan Perhutanan Sosial Kementerian Kehutanan Nomor: P.3V-SET/2013 tanggal 26 Juli 2013 tentang Petunjuk Teknis Penyusunan Data Spasial Lahan Kritis. Jakarta: Direktorat Jenderal Bina Pengelolaan DAS dan Perhutanan Sosial, Kementerian Kehutanan RI. https://www.academia.edu/28838368/PERDIRJEN_BINA_PENGELOLAAN_DAERAH_ALIRAN_SUNGAI_DAN_PERHUTANAN_SOSIAL_NOMOR_P_4_V_SET_2013_TENTANG_PETUNJUK_TEKNIS_PENYUSUNAN_DATA_SPASIAL_LAHAN_KRITIS

Peraturan Pemerintah (PP RI) No.P.37 Tahun 2012 tentang Pengelolaan DAS. 1 Maret 2012. Jakarta, Indonesia: Lembaran Negara Republik Indonesia Tahun 2012 Nomor 62. https://peraturan.bpk.go.id/Home/Details/5249

Peraturan Daerah Provinsi Bali (PERDA) No. 16 Tahun 2009 tentang Rencana Tata Ruang Wilayah Provinsi Bali Tahun 2009 – 2029. 28 Desember 2009. Denpasar: Lembaran Daerah Provinsi Bali Tahun 2009 Nomor 16. https://jdih.baliprov.go.id/uploads/produkhukum/peraturan/2009/perda/2009perda0051016.pdf

Pratiwi, K. 2012. Aplikasi Pengolahan Digital Citra Penginderaan Jauh dan Sistem Informasi Geografis Untuk Pemetaan Lahan Kritis Kasus Di Kabupaten Banjarnegara Provinsi Jawa Tengah. http://lib.geo.ugm.ac.id/ojs/index.php/jbi/article/view/51/50

Restu. 2014. "Analisis Kecenderungan Potensi Erosi Di Daerah Aliran Sungai (DAS) Tukad Pakerisan" (tesis). Universitas Mahasaraswati Denpasar. https://docplayer.info/43627243-Identifikasi-pemetaan-lahan-kritis-das-pakerisan-berbasis-penginderaan-jauh-dan-sistem-informasi-geografis-untuk-daya-dukung-lahan-berkelanjutan.html

Syam, A. 2003. Sistem Pengelolaan Lahan Kering Di Daerah Aliran Sungai Bagian Hulu. *Jurnal Litbang Pertanian, 22*(4). https://www.academia.edu/download/30475638/p3224035.pdf

Widayani, 2015. "Evaluasi Banyaknya Tanah Tererosi Di Sepanjang DAS Tukad Pakerisan" (tesis). Universitas Mahasaraswati Denpasar. https://web.archive.org/web/20180411110003id_/http://ojs.unmas.ac.id/index.php/pros/article/viewFile/327/291