Land Use Change and Its Impact on the Water Balance in Sumitro Sub-Watershed

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Abstract. Kulonprogo Regency is projected to experience population growth, increasing basic needs such as food, raw materials, settlements, and development activities. The Sumitro Sub-Watershed is upstream of the Serang Watershed, which is a critical watershed. It has a high level of damage due to changes in land cover, resulting in high erosion, flooding, and drought. This study aimed to determine the land use change, the water balance and their relationships. This research also formulated the optimal form of land use to improve water storage capacity and reduce runoff in the Sumitro Sub-Watershed area. This study uses the Thornthwaite-Mather method. The calculation of the water balance analysis is based on 12 land-use changes from 2011 to 2022. The land use directive adopts the concept of agroforestry by considering the spatial plans of the Kulon Progo Regency. The study results showed that land use in the Sumitro SubWatershed had changed, causing the condition of the water balance also to change. A land use change of 8.08% has led to a change in water storage capacity (WHC). Land use direction with the agroforestry concept can increase water storage capacity by 60.04 mm and reduce runoff value.

1. Introduction

Based on data from the central statistical agency, Kulon Progo Regency is estimated to experience an increase in population from year to year [1]. This is due to the increase in basic needs, which leads to increased land demand. If this situation continues to occur, it will result in degradation in the watershed [2]. Watershed is a spatial unity consisting of abiotic elements (soil, water, air) and biotic elements (vegetation, animals, other living organisms, and human activities) that interact and relate to each other so that they can become a unified ecosystem [3].

One of the watersheds in Kulonprogo Regency is the Serang Watershed. Based on the Decree Minister of Forestry Number 328/Menhut-II/2009, the Serang watershed has been designated as a watershed with critical conditions in Indonesia, and based on the Regional Regulation of D.I Yogyakarta Number 11 of 2016, the Serang watershed is a priority watershed management target for the restoration of the watershed environment from the physical and socio-economic aspects of the community [4] [5].

The Serang watershed has various problems, namely massive land conversion, changes in environmental conditions, crop failure due to overflowing water discharge in the upstream part, damage to the downstream, illegal mining, fluctuations in water discharge in the rainy and dry season that are quite high, siltation due to land utilization for agricultural activities, and problems in social, economic, cultural and other institutional aspects. The Sumitro Sub-Watershed is the upstream part of the Serang Watershed which has the potential to become a regulator of environmental services but has a high damage condition. Changes in land cover will cause a decrease in watershed function, causing critical land, erosion, flooding, and drought [6] [7]. To overcome these problems, it is necessary to optimize land use for environmentally friendly purposes and aim to improve the condition of the sub-watershed to produce sustainable water productivity for the common good [6].

2. Research Methods

2.1 Tools and Materials

The tools used in this study include ArcGIS Software, Microsoft Excel Software, stationery, cameras, labels, shovels, plastic bags, Global Positioning System (GPS), Avenza Software, and mobile phones. Meanwhile, the materials used in this study can be seen in the following table:

Table 1. Materials used

No.	Data Type	Source
1	Rainfall Data, Coordinates and Elevation of Rainfall Measuring Stations 2011 and 2022	Public Works, Housing and Energy Mineral Resources Office of Yogyakarta, Meteorology, Climatology, and Geophysics Agency (BMKG) of the Mlati Climatology Station, Sleman.
2	Temperature, Coordinates and Elevation data of	Public Works, Housing and Energy Office of Mineral Resources of Yogyakarta.

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	Climatology stations 2011 and 2023	
3	Map of the administrative area of the research location (scale 1:25,000)	Serayu Opak Progo Watershed Management Center
4	Land Use Map (1:25,000 scale)	Forest Area Stabilization Center Region XI Yogyakarta
5	Soil Type Map (1:25,000 scale)	Serayu Opak Progo Watershed Management Center
6	Soil Texture	Primary Data

2.2 Method

This study analyzed water balance using the Thornthwaite & Mather method (1957). This method requires data inputs, including rainfall, air temperature, evaporation, land cover data, and soil conditions from field observations [8]. Field data collection for texture analysis is based on land use change maps by intersecting the 2022 land-use change map and the 2011 land use map as shown in picture 1 . Point determination using the purposive sampling method for each land use change is carried out 3 times.

The water balance analysis was calculated every month in 2011 and 2022. This analysis explains the relationship between land use and the water capacity that the soil and the state of the water balance can store. Furthermore, the information generated will be used as a direction for optimal land use conditions. The water balance parameters used in this method are air temperature, rainfall (P), potential evapotranspiration (ETP), P-ETP, accumulation potential water loss, available water capacity, soil moisture, changes in water content values, actual evapotranspiration (ETA), deficits, surpluses, runoff, Drought Index, Koefesien runoff.

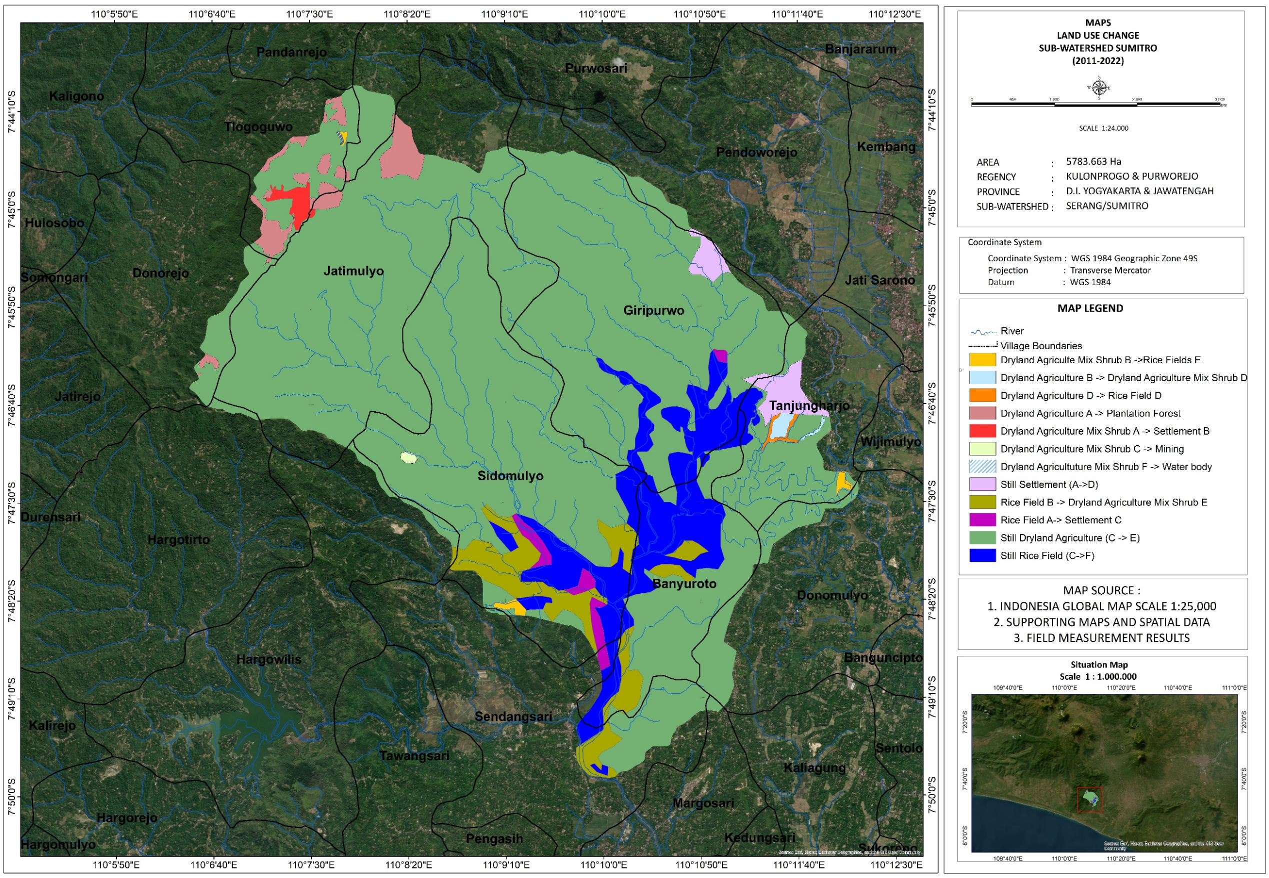

Figure 1. Land Use Change Sub-Watershed Sumitro Map

3. Results and Discussion

3.1 Land Use Change

Land use changes that occurred in the Sumitro sub-watershed covered an area of 8.08% of the total area of the sub-watershed or an area of 463.81 hectares from 5783.66 hectares. In more detail, it can be seen in Table 2, the wide change in each land use. The biggest change was obtained by the use of rice fields with an area of 268 hectares. This number decreased from 2011 – 2022. The absence of incentives for farmers can cause a significant decline in the rice field areas, so there is no reason to maintain the rice fields they manage [9]. Drought events that often occur in this region are the reason for the decrease in rice fields and the increase in the use of water body land. The use of water body land is used for conservation, raw water, and irrigation. Furthermore, the use of dryland agricultural land is used by the community for agriculture and gardening.

Table 2. Changes in each land use

Land Use	2011 (Ha)	2022 (Ha)	Change Area (Ha)
Plantation Forest	0	118	118
Settlement	22	90	68
Water Body	0	1	1
Dryland Agriculture Mixed Shrubs (DLAMS)	4.919	5.016	96
Rice Fields	824	556	-268
Mining	0	4	4
Dryland Agriculture	18	0	-18
Sum	5.784	5.784	0

3.2 Temperature and Rainfall

The air temperature in 2011 was higher than in 2022 (Fig. 2). On the other hand, the rainfall parameters in 2011 were smaller than in 2022 (Fig. 3). Temperature changes can occur due to various influencing factors, namely sunlight intensity, rainfall, air pollution, air humidity, and the development of built land [10][11]. Furthermore, rainfall is an element that is related to other weather elements such as temperature, humidity, wind speed, and wind direction [12]. Therefore, it can be concluded that the two parameters affect each other.

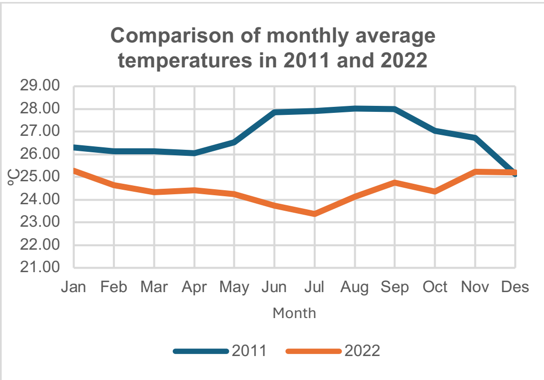

Figure 2. Comparison of monthly average temperatures in 2011 and 2022

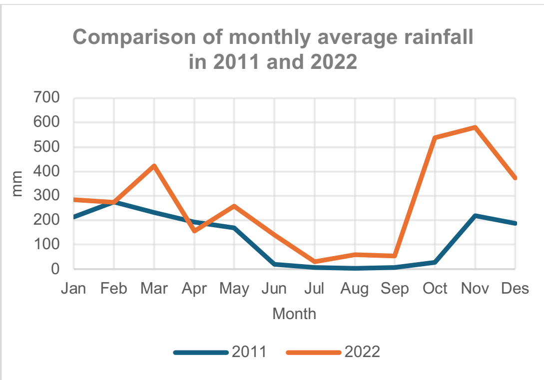

Figure 3. Comparison of monthly average rainfall in 2011 and 2022

3.3 Soil Texture

The soil texture is used as a material for calculating *water holding capacity.* Soil texture analysis uses the pipette method with 3 repetitions for each land use change. The results of the analysis can be seen in Table 3. The soil texture depicts the relative comparison of dust, sand, and clay particles. Each fraction has a different particle force that affects the soil's ability to hold water. The more sand fractions, the lower the soil's ability to hold water, and vice versa, the more dust will higher the soil's ability to hold water [13].

Soil texture affects other physical properties of soil, namely BV (Bulk Volume*),* Total Pore Space, Soil Moisture, and Soil Structure. The rougher the texture will have a high BV value; this determines the level of density and development of plant roots. The higher the BV value, the lower the pore scale, this determines the value of the maximum capacity of water retained in the soil. Soils with abundant macropores have good aeration but poor retention, while soils with few macropores have poor aeration and good water retention. The ideal condition for plant growth is when the soil is able to provide a balance between aeration and water retention for plant growth. This can be obtained by adding organic matter to modify the influence of texture to create a crumb structure that has balanced macro and micro pores [14].

Table 3. Results of soil texture analysis

Land Use Change	%SAND	%DUST	%SILT	Soil Texture
Dryland Agriculture A to Plantation Forests	51,84	32,41	15,74	Loam
Dryland Agriculture Mixes Shrub A to Settlement B	39,97	18,60	41,43	Clay
Rice Field A to Settlement C	64,97	13,68	21,35	Sandy clay loam
Stay Residential (A to D)	42,55	28,08	29,37	Clay Loam
Dryland Agriculture B to Dryland Agriculture Mix Shrub D	38,76	50,84	10,40	Silty loam
Fixed Dryland Agriculture (C to E)	71,19	23,39	5,41	Sandy Loam
Rice Field B to Dryland Agriculture Mixed with Shrub E	28,29	55,69	16,02	Silty loam
Dryland Agriculture D to Rice Fields D	39,57	53,51	6,92	Silty loam
Dryland Agriculture Mixes Shrub B to Rice Field E	18,15	34,26	47,58	Clay
Fixed Rice Fields (C to F)	35,92	43,93	20,15	Loam
Dryland Agriculture Mixes Shrub C to Mining	86,76	7,83	5,40	Loamy sand

3.4 *Water Holding Capacity*

The water holding capacity (WHC) value is the maximum water thickness (mm) that can be stored at each depth of the soil layer. The value of WHC depends on the type of soil (texture) and the depth of the plant's roots [15]. In Table 4. obtained WHC values in 2011 and 2022. In that span of years, there was a change in land use due to anthropogenic activities. This will affect groundwater flow, actual evapotranspiration, runoff*, and* total *water yield* [16].

Table 4. WHC values in 2011 and 2022

Land Use Change 2011	WHC 2011	Land Use Change 2022	WHC 2022
Dryland Agriculture A	285	Plantation Forest	367
Dryland Agriculture Mixed Shrub A	201	Settlement B	0
Rice Field A	115	Settlement C	0
Settlement A	0	Settlement D	0
Dryland Agriculture B	300	Dryland Agriculture Mix Shrub D	300
Dryland Agriculture C	251	Dryland Agriculture E	251
Rice Field B	124	Dry Land Agriculture Mix Shrub E	300
Dryland Agriculture D	300	Rice Field D	124
Dry Land Agriculture Mixed Shrub B	200	Rice Field E	75
Rice Field C	112	Rice Field F	112
Dry Land Agriculture Mixed Shrub C	182	Mining	0

Of these changes, there are only two changes in land use that have increased the value of available water capacity (WHC), namely from dry land use A to plantation forests and rice fields B to dryland agriculture mixed with shrub E, while nine land use changes have a fixed and declined available water capacity value. The most significant decline occurred in areas that were converted into settlements and mining because both did not have root zones.

3.5 Water Balance in 2011 and 2022

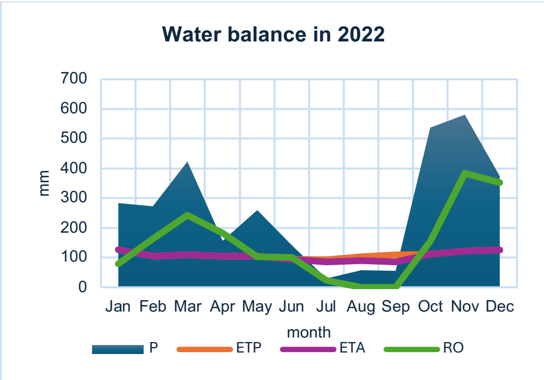

Figure 4. Water balance in 2022

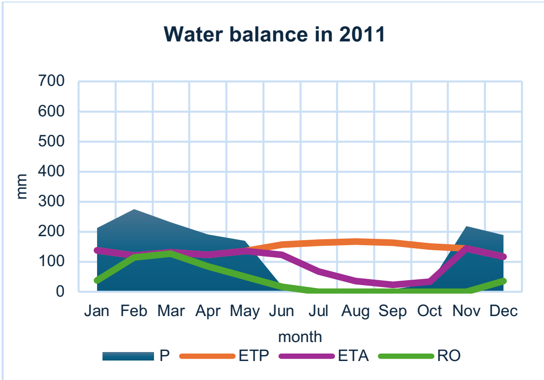

Figure 5. Water balance in 2011

Table 5. Water balance values in 2022 and 2011

2022

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	283	273	424	156	259	141	30	58	55	538	581	373
ETP	125	104	109	105	104	94	93	103	110	110	123	126
ETA	125	104	109	105	104	94	85	90	86	110	123	126
R	79	163	242	183	103	101	24	0	0	155	384	353

2011

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CH	213	275	231	192	169	19	6	3	8	27	218	189
ETP	138	121	131	124	135	156	163	167	164	151	144	117
ETA	138	121	131	124	135	122	69	35	23	33	144	117
R	37	115	127	84	51	17	0	0	0	0	0	36

Figures 4 and 5, along with Table 5, present the water balance in 2022 and 2011. Each line in the graph depicts precipitation (P), actual evapotranspiration (EA), potential evapotranspiration (EP), and run off (RO). precipitation is the amount of rainfall each month, actual evapotranspiration is evapotranspiration which takes into account the condition of vegetation and the land surface [17]. Thirdly there is potential evapotranspiration (ETP) which is the amount of evapotranspiration that occurs due to excess water supplies, and finally run off (RO) which is water that moves above the land surface and then moves towards rivers, lakes and oceans [18].

The two graphs have different precipitation intensities in 2022, the highest rainfall occurs in November with rainfall of 581 mm/m and the lowest in July with rainfall of 30 mm/m. It can be seen in the graph, January - June and October - December are wet months because in those months the P line is above the ETP line, while July-September are dry months because the P line is below the ETP line so that in total there are 9 wet months and 3 dry months. dry. It can be seen in the graph, the ETA line coincides with the ETP line, except in the dry months because in those months there is a change in soil moisture due to the soil not being saturated, as happens in the wet months.

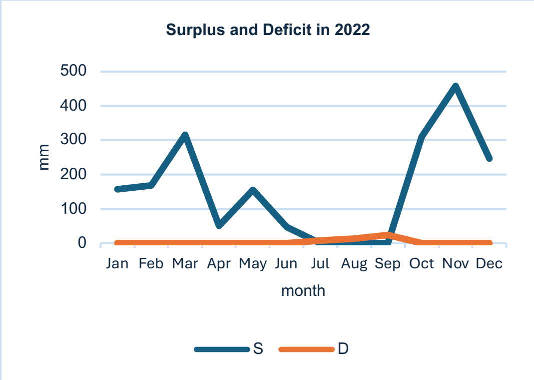

Figure 6. Surplus and Deficit in 2022

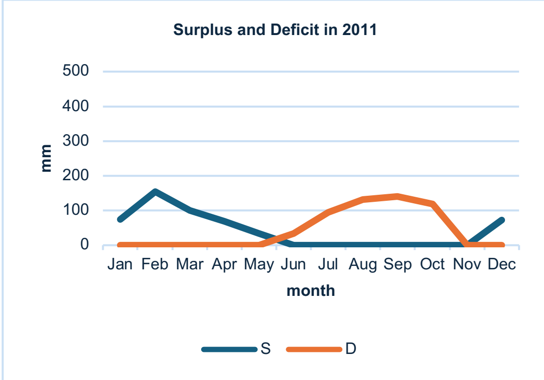

Figure 7. Surplus and Deficit in 2011

Table 6. Surplus and deficit values

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2022												
S	158	169	315	52	155	47	0	0	0	310	458	247
D	0	0	0	0	0	0	7	13	24	0	0	0
2011												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
S	75	154	100	68	35	0	0	0	0	0	0	72
D	0	0	0	0	0	34	95	132	140	118	0	0

Figures 6 and 7, along with Table 6, show the surplus (S) and deficit (D) values for each month. It was found that the surplus value was in line with rainfall, except in the dry months, because in the dry months, there was a water deficit due to changes in soil moisture. The highest runoff value is the same as rainfall in November, but the lowest runoff value is in September because the runoff value is half the surplus value and half of the previous month.

A significant difference occurred in 2011 compared to 2022. In 2011 the dry months occurred in June-October. It can be seen in Figure 5 that the ETP line is below P, while the wet months occurred in January-May and November – December, so there were 5 dry months and 7 wet months. The highest rainfall occurred in February, and the surplus value touched the highest figure with a value of 275 mm/m. However, in the following month, there was a downward trend until it reached 3 mm/m in June and then increased again. Compared to 2022, this year, there is a large gap in ETA and ETP due to changes in soil moisture that occurred during the 5 dry months. Surplus and deficit values have an opposite relationship, as shown in the graph. The highest deficit value occurred in September. This is different from 2022, which occurs at the end of the dry month because, in October, there is a decrease in temperature, which affects the ETP value, which also decreases.

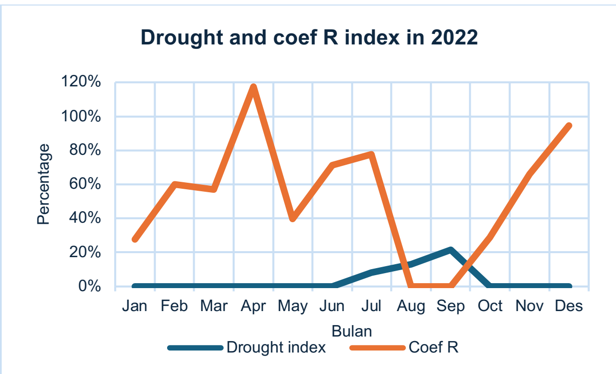

Figure 8. Drought and coef r index in 2022

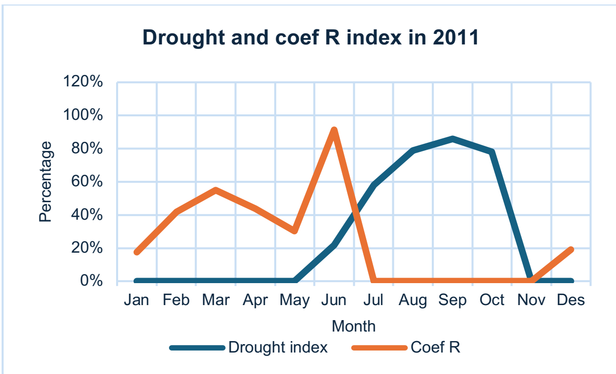

Figure 9. Drought and coef r index in 2011

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The drought index occurs in the dry months. There are 3 categories of drought index, namely low (0%-16.7%), moderate (16.7%-33.3%), and severe (>33.3%) [19]. In 2022 (Fig. 8), there are two categories of drought indexes: low in July and August and moderate in September. In the drought index in 2011 (Fig. 9), there is no low drought index, but there are four months with high drought levels, namely July, August, September, and October. Furthermore, there is one month with a moderate drought level, namely in June. The drought index is obtained by dividing the deficit value and the potential evapotranspiration. The drought index value in 2011 is higher than in 2022 due to low rainfall in that year, so the deficit value will be high.

The difference in coefficient R is calculated by dividing *the* runoff by the rainfall value. In July, August, September, October, and November of 2011, the coefficient value of R 0 due to the month is not a wet month. The highest value in 2011 was in June, with a percentage of 91%, while in 2022, the highest value was in April, with a percentage of 117%, and the months that had a coefficient value of R 0 only existed in two months, namely August and September because only in those two months did not have a runoff *value.*

3.6 Drought Index on Various Land Uses

The drought index is a method of providing a quantitative estimate of the drought level in an area [20]. Based on Figure 10, only July, August, and September of 2022 have drought index values. The land use with the largest drought index is in settlements and mining because both do not have a root zone, so the WHC value is 0, and the deficit value and drought index are also high. Then the next largest drought index, namely the use of rice fields because rice fields are filled with shallow-rooted plants. There are three uses of rice fields with different textures. Rice fields E with clay texture have the largest drought index. Furthermore, rice field F has a clay texture and then rice field D has a dusty clay texture. The smallest drought index is obtained by using plantation forest land because plantation forests are filled with vegetation with long roots, which can certainly increase the ability to hold water.

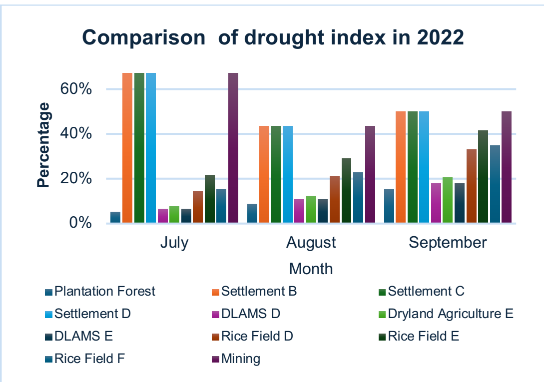

Figure 10. Comparison of drought index in 2022

The Drought Index in 2011 (figure 11) is highest by residential land use in the range of 82%-98%. The highest drought index occurred in August, influenced by the rainfall factor in that month, which was the driest month throughout 2011 and 2022, with an average rainfall of only 3.21 mm/m. Furthermore, the next largest land use index is rice fields. Just like in 2022 (figure 10), rice fields have a high drought index value due to vegetation that has short roots, so the ability to hold water is low. Texture also affects water capability and how easily the roots can penetrate deeper into the soil [21]. The order of rice field land use texture with the largest drought index is the use of rice field C with clay texture, rice field A with sandy clay texture, and rice field B with dusty clay texture. Furthermore, the smallest drought index is obtained using dryland agricultural land. There are 4 dryland farms with different textures: clay, sandy clay, and 2 land uses with a dusty clay texture. The largest dryness index value is found in dryland agriculture with sandy clay texture because the sand fraction has a low water holding capacity [22].

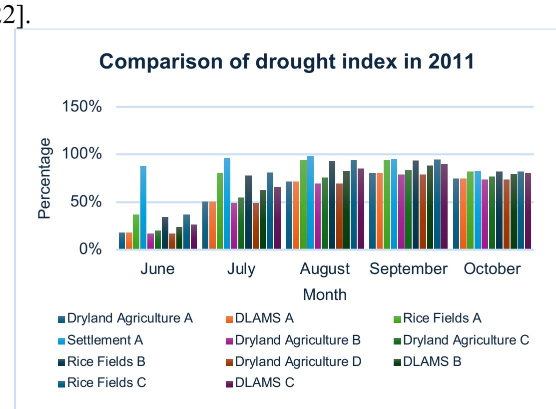

Figure 11. Comparison of drought index in 2011

3.7 Koefesien Runoff on Various Land Uses

Surface flow coefficient (C) is a number that compares the amount of surface flow and the amount of rainfall. The C value is an indicator to determine the physical condition of a watershed. The closer it is to 0, the better the watershed is, and vice versa, if it is close to 1, the condition of the watershed is getting worse [23]. In Figure 13, 2 months have different runoff coefficient values. The difference in value is only obtained using residential land that cannot hold water, so the runoff coefficient value is greater than other land uses. Residential land use in November is relatively low (<20%) because this month is the beginning of the wet month from the dry month, so the soil is not saturated.

The difference in the coefficient value *of* runoff is caused by the flow of water entering the soil according to the water capacity that can be held in each land use. The highest value was obtained by land use that has soil capacity with low water capacity, namely mining and settlements (figure 12). On the contrary, the lowest score is obtained by plantation forests because they have soil capabilities with high water capacity so that they can store water better.

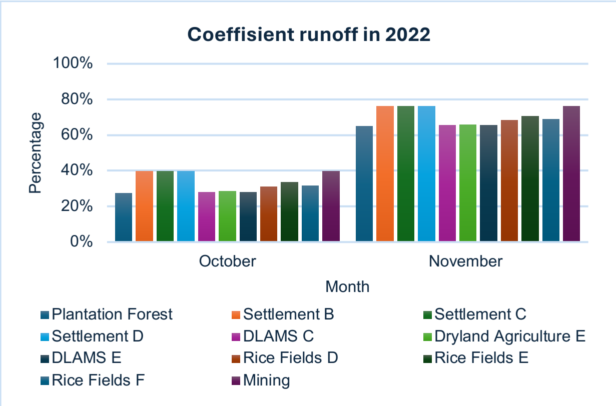

Figure 12. The runoff coefficient in 2022

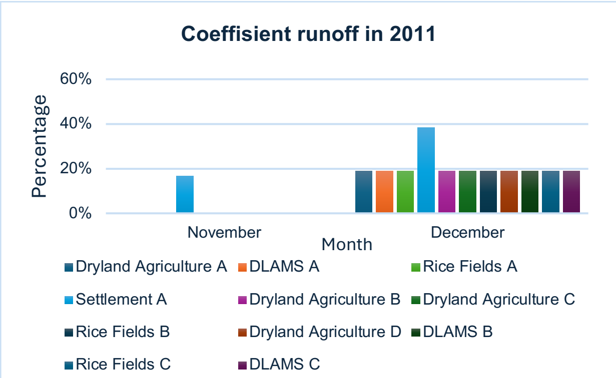

Figure 13. The runoff coefficient in 2011

3.8 Land Use Directive

Based on the results of the relationship between land use changes and water balance, the land use change simulation focuses on controlling runoff and paying attention to the drought index for more optimal land use. The direction of this research aims to predict an increase in WHC by changing traditional land use to agroforestry patterns or other more optimal land uses. The formulation of land use direction design is guided by the Regional Spatial Planning (RTRW) of Kulon Progo Regency for 2012-2032 [24].

Agroforestry is a land use system that integrates trees or woody plants with agricultural plants and/or livestock in a land unit. Agroforestry combines agricultural and forestry components to create mutually beneficial interactions between various elements in the agricultural ecosystem. The agroforestry concept aims to utilize existing resources sustainably and optimally [25]. Types of woody plant vegetation are selected that have conservation value and economic value so that the community can optimally receive the impact. The conservation value of trees is to protect, prevent, and overcome environmental problems such as runoff, landslides, and erosion [26]. Longer roots can significantly increase the soil's capacity to hold water. The plant root system influences the structure of soil porosity and its retention capacity by forming pathways that increase infiltration and water retention [27]. Trees have various functions during the dry season, namely as temperature regulators by providing shade through their leaves, which reduces soil surface heating and reduces water evaporation from the soil. In addition, fallen leaves and dead roots provide organic matter for the soil, increasing the availability of nutrients for other plants and microorganisms and balancing aeration with drainage in the soil. Thus, the role of trees is very vital in maintaining water availability, protecting the soil, and supporting the continuity of the ecosystem.

Rice fields can be used using the Agrosilviculture model, namely a combination of food crops such as rice with trees or woody plants. Several studies have stated that fruit trees such as mango, guava, and hardwood trees such as sengon (*Paraserianthes spp.*) can be planted on embankments or edges of rice fields. The aim is to maximize space and increase water storage capacity without disturbing rice growth. Research in Indonesia has shown many increases in productivity, such as planting sengon (*Paraserianthes spp.*) with rice, as long as the spacing and variety types can be managed well [28]. The composition of agroforestry in dry land farming and dry land farming mixed with shrubs is filled with filler plants, such as fruit trees, higher plants in the form of perennials such as acacia (*Acacia sp.*) or Sengon (*Albizia chinensis*), undergrowth, and agricultural crops as the main crop. The selection of plant types considers those that have interception, evapotranspiration, and root stability functions. In the use of plantation forest land, plants can be added, such as coffee (*Coffea canephora*), which is shade tolerant. Pine plantations *(Pinus merkusii*) and coffee plants together help prevent soil erosion and increase water infiltration thereby maintaining soil and water quality [29]. For residential land use, home gardens and boundary plantation models can be used [30]. These two models can utilize limited land around the house to plant woody plants, fruit, medicine, and food with shade trees in the yard. Land use directions, more concisely, can be seen in Table 7.

Table 7. Land Use Directive

No	Land use	Land Use Directive
1	Settlement	Plant woody plants / medicinal plants / fruit plants with shade trees in the yard
2	Dryland agriculture and dryland agriculture mixed shrub.	Planted composition of filler plants, such as fruit trees, higher plants in the form of perennials, and agricultural crops as the main plants by considering the interception function.
3	Rice fields	Plant woody plants and fruit plants on embankments or edges of rice fields, paying attention to planting distance and type of vegetation.
4	Plantation forest	Plant plants that are shade tolerant and suitable for pine forests (P*inus merkusii*) such as

	coffee plants (*Coffea canephora*)

The directive succeeded in increasing the water capacity value shown in Table 8, increasing by 60.04 mm from the previous 234.91 mm to 294.95 mm after modification with the agroforestry concept. The thing that was modified was the root zone so that the water holding capacity value increased. High water holding capacity will better store water for plants, help plants stay hydrated longer during dry periods, increase yields, reduce the need for additional irrigation, help maintain water balance, and reduce the risk of flooding by absorbing more rainwater.

Table 8. WHC results after modification

Land Use	Texture	Available Water Capacity	Rooting Zone (m)	Area (%)	AWC (mm)
Plantation Forest	Clay	183,333	2,5	2,03%	9,3
Settlement B	Clay	300	0,25	0,40%	0,3
Settlement C	Sandy clay	225	0,51	0,78%	0,9
Settlement D	Clay clay	250	1,6	1,45%	5,8
Dryland Agriculture Mixed Shrub D	Dusty clay	200	2	0,20%	0,8
Dryland Agriculture E	Sandy loam	150	2	81,25%	243,8
Dryland Agriculture Mixed Shrub E	Dusty clay	200	2	4,20%	16,8
Rice Fields D	Dusty clay	200	1	0,12%	0,2
Rice Fields E	Clay	300	0,5	0,23%	0,3
Rice Fields F	Clay	180,333	1	9,27%	16,7
Mining	Loamy sand	116,667	0	0,06%	0,0
TOTAL					294,95

Land use modification is expected to improve the quality of the watershed and be useful for the local community. Considerations from social, ecological, and economic aspects must be considered carefully so that they can be implemented and sustainable. The concept of agroforestry is a solution to land-related problems. The agroforestry concept will increase economic and ecological value [31]. There needs to be guidance for the community and multi-party cooperation to implement the plan in accordance with the Kulon Progo Regency RTRW 2012-2032.

4. Conclusion

Land use in the Sumitro Sub-DAS experienced 12 changes between 2011-2022. The largest change was rice fields to dryland agriculture mixed with shrubs (242.91 Ha or 4.2%), followed by dryland agriculture mixed with shrubs to plantation forests (117.53 Ha or 2.03%). There were 6 other changes with an area below 1%. Three types of land remained unchanged, with dryland agriculture mixed with shrubs being the largest (4731.08 Ha or 81.8%). The water balance showed an increase in surplus and runoff coefficient, while the deficit and drought index decreased. Land use changes affected the water balance, especially water holding capacity (WHC). Of the 12 changes, only two increased WHC, namely from dryland agriculture to plantation forests and rice fields to dryland agriculture mixed with shrubs. Four types of changes had constant WHC, and five others decreased. This decrease in WHC increases the runoff coefficient and drought index so that the best water balance occurred in 2011.

Land use guidelines to reduce the runoff coefficient and increase the water retention capacity (WHC) in the Sumitro Sub-DAS are carried out by modifying the use of dry land agricultural land and dry land mixed with shrubs with the agroforestry concept, namely by planting filler plants, such as fruit trees, higher plants in the form of perennials, and agricultural crops as the main crop. The guidelines for using rice fields are to plant woody plants and fruit plants on the embankments or edges of rice fields by paying attention to the planting distance and type of residential vegetation. For the guidelines for using residential land, medicinal plants, fruit, and wood can be planted in the yard. Finally, the guidelines for the use of plantation forests can be planted with coffee plants (*Coffeea arborea*) or other types of plants that are shade tolerant and suitable for pine plantation forests *(Pinus merkusii*). The results of the modification experienced an increase in the WHC value of 60.04 mm from the previous 234.91 mm to 294.95 mm.

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Bibliography

1. BPS Kabupaten Kulon Progo, Proyeksi Jumlah Penduduk (Jiwa), 2018-2020, acccessed at https://kulonprogokab.bps.go.id/indicator/12/297/1/proyeksi-jumlah.penduduk.html (2021). Accessed on February 27, 2024
2. N. Ariyani, D.O. Ariyanti, M. Ramadhan, Pengaturan ideal tentang pengelolaan daerah aliran sungai di Indonesia (Studi di Sungai Serang Kabupaten Kulon Progo). Jurnal Hukum Ius Quia Iustum **27**(3), 592–614 (2020).
3. N.P.V. Fitriani, Analisis Debit Air di Daerah Aliran Sungai (DAS). Jurnal Ilmu Teknik **2**(2) (2022).
4. Pemerintah Daerah Daerah Istimewa Yogyakarta, Nomor 11 Tahun 2016 Tentang Pengelolaan Daerah Aliran Sungai (2016).
5. Keputusan Menteri Kehutanan Republik Indonesia, Nomor: SK. 328/Menhut-II/2009 Tentang Penetapan Daerah Aliran Sungai (DAS) Prioritas Dalam Rangka Rencana Pembangunan Jangka Menengah (RPJM) Tahun 2010-2014 (2009).
6. A. Setyawan, T. Gunawan, S. Dibyosaputro, S.R. Giyarsih, Jasa dan etika lingkungan untuk pengendalian air dan banjir sebagai dasar pengelolaan DAS Serang. Jurnal Pembangunan Wilayah dan Kota **14**(4), 241–251 (2019).
7. A.G. Salim, I.W.S. Dharmawan, B.H. Narendra, Pengaruh Perubahan Luas Tutupan Lahan Hutan Terhadap Karakteristik Hidrologi DAS Citarum Hulu. Jurnal Ilmu Lingkungan **17**(2), 333–340 (2019).

8. P. Hartanto, Perhitungan neraca air DAS Cidanau menggunakan metode thornthwaite. Ris. Geo. Tam. **27**(2), 213–225 (2017).
9. S. Mulyani, A.T. Fathani, E.P. Purnomo, Perlindungan Lahan Sawah Dalam Pencapaian Ketahanan Pangan Nasional. Rona Teknik Pertanian **13**(2), 29–41 (2020).
10. S. Liwan, P.C. Latue, Analisis Spasial Perubahan Suhu Permukaan Daratan Kota Kupang Menggunakan Pendekatan Geospatial Artificial Intelligence (GeoAI). Buana Jurnal Geografi, Ekologi Dan Kebencanaan **1**(1), 14–20 (2023).
11. A.N. Hamidy, S. Sudarti, Y. Yushardi, Analisis Perubahan Suhu Lingkungan Terhadap Kenyamanan Masyarakat Di Desa Sumber Tengah. Jurnal Pembelajaran Fisika **10**, 70–76 (2021).
12. M.W.A. Azkia, N. Hitayuwana, Z.A. Khusna, E. Widodo, Analisis temperature dan Kelembaban terhadap Curah Hujan di Kabupaten Sleman Provinsi Daerah Istimewa Yogyakarta, in Prosiding Konferensi Nasional Penelitian Matematika dan Pembelajarannya (KNPMP) IV (2019).
13. D. Rahmadani, P.E. Sasongko, K. Wijaya, Kajian Kemampuan Tanah Dalam Menahan Air Pada Tiga Satuan Penggunaan Lahan Di Desa Karangpatihan Kecamatan Balong Kabupaten Ponorogo. Jurnal Ilmu-Ilmu Pertanian Indonesia **25**, 66–73 (2023).
14. Y. Yulnafatmawita, A. Asmar, A. Ramayani, Kajian sifat fisika empat tanah utama di sumatera barat. Jurnal Solum **4**, 81–90 (2007).
15. M. Abbas, B. Rasyid, M. Achmad, Potensi Ketersedian Air Tanah dan Neraca Air Tanah dan Neraca Air Wilayah Karst Di Kabupaten Maros: Potential Availability of Groundwater and Water Balance of Karst Area in Maros Regency. Jurnal Ecosolum **11**(1), 95–109 (2022).
16. A.A. Shawul, S. Chakma, A.M. Melesse, The response of water balance components to land cover change based on hydrologic modeling and partial least squares regression (PLSR) analysis in the Upper Awash Basin. Journal of Hydrology: Regional Studies **26**, 100640 (2019).
17. I. Damayanti, B. Santosa, Analisis Optimasi Pola Tata Tanam Jaringan Irigasi Daerah Irigasi Cidurian Tangerang Menggunakan Program Linier. Teras Jurnal **12**(1), 281–294 (2022).
18. C. Asdak, Hidrologi dan pengelolaan daerah aliran sungai (UGM Press, Yogyakarta, 2022).
19. ILACO B.V., Agricultural Compendium For Rural Development In The Tropics and subtropics (Elsevier Science Publishing Company INC, Amsterdam, 1985).
20. S.N. Aripbilah, H. Suprapto, Analisis kekeringan di Kabupaten Sragen dengan metode Palmer, Thornthwaite, dan standardized precipitation index. Jurnal Sumber Daya Air **17**(2), 111–124 (2021).
21. M. Mustawa, S.H. Abdullah, G.M.D. Putra, Analisis efisiensi irigasi tetes pada berbagai tekstur tanah untuk tanaman sawi (*Brassica juncea*). Jurnal Ilmiah Rekayasa Pertanian dan Biosistem **5**(2), 408–421 (2017).
22. A. Alshankiti, Integrated Plant Nutrient Management for Sandy Soil Using Chemical Fertilizers, Compost, Biochar and Biofertilizers Case Study in UAE. J. Arid Land Stud. **26**, 101–106 (2016).
23. G.P. Verrina, D.D. Anugerah, H. Haki, Analisa runoff pada Sub DAS Lematang hulu. Doctoral dissertation, Sriwijaya University (2013).
24. Peraturan Daerah Kabupaten Kulon Progo, Nomor 1 Tahun 2012 Tentang Rencana Tata Ruang Wilayah Kabupaten Kulon Progo Tahun 2012-2032 (2012).
25. M. Purba, A. Marsela, R. Mustika, R. Subakti, S. Khairani, A.B. Suwardi, Potensi Pengembangan Agroforestri Berbasis Tumbuhan Buah Lokal. Jurnal Ilmiah Pertanian **17**(1), 27–34 (2020).
26. W. Seran, L.M.R. Kaho, M.E. Pellendo'u, Penanaman Pohon dan Pembersihan Sampah di Kelurahan Liliba, Kota Kupang. Community Development Journal: Jurnal Pengabdian Masyarakat **4**(6), 11945–11947 (2023).
27. X. Wang, Z. Li, Y. Chen, Y. Yao, Influence of Vetiver Root Morphology on Soil–Water Characteristics of Plant-Covered Slope Soil in South Central China. Sustainability **15**(2), 1365 (2023). https://doi.org/10.3390/su15021365
28. F. Sopacua, N. Wijayanto, D. Wirnas, Growth of three types of sengon (*Paraserianthes* spp.) in varying planting spaces in agroforestry system. Biodiversitas Journal of Biological Diversity **22**(10), 4423–4430 (2021).
29. E.D. Cahyono, S. Fairuzzana, D. Willianto, E. Pradesti, N.P. McNamara, R.L. Rowe, M.V. Noordwijk, Agroforestry innovation through planned farmer behavior: trimming in pine–coffee systems. Land **9**(10), 363 (2021).
30. R.K. Singh, M.D. Behera, P. Das, J. Rizvi, S.K. Dhyani, Ç.M. Biradar, Agroforestry suitability for planning site-specific interventions using machine learning approaches. Sustainability **14**(9), 5189 (2022).
31. H. Mayrowani, Ashari, Pengembangan Agroforestry Untuk Mendukung Ketahanan Pangan dan Pemberdayaan Petani Sekitar Hutan. Forum Penelitian Agro Ekonomi **29**(2), 83–98 (2024). https://epublikasi.pertanian.go.id/berkala/fae/article/view/3543