JOIV : Int. J. Inform. Visualization, 9(1) - January 2025 57-64

INTERNATIONAL JOURNAL ON INFORMATICS VISUALIZATION

journal homepage : www.joiv.org/index.php/joiv

Simulation of Land Use and Land Cover of Peatland Bengkalis Using QGIS

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Abstract*—The phenomenon of forest and peatland fires in Bengkalis Regency is inseparable from the change in land use and cover (LULC). The dynamic LULC in Bengkalis Regency is caused by economic factors sourced from land-based resource management. As a result, negative impacts such as environmental damage can trigger fires. Therefore, this study attempts to observe the LULC patterns on peatlands in the Bengkalis Regency using overlay techniques using QGIS. QGIS functions unlock the software's full potential, empowering you to manipulate data, automate workflows, create custom expressions, and perform advanced spatial analysis—all within a single platform. There are 12 LULC that can be identified on peatlands in Bengkalis Regency, including plantations (42.98%), primary forests (42.68%), shrubs (12.29%), residential and activity areas (0.71%), fields/farmlands (0.64%), lakes/ponds (0.43%), empty/bare land (0.18%), rivers (0.05%), and ponds, ponds, mangrove forests, and rice fields ranging from 0.004% to 0.008%. In addition, in the Bengkalis Regency, concession areas of at least 175,081.19 Ha are in the Peatland Ecosystem Protection Function (FLEG). LULC simulation provides a powerful tool for assessing the potential impact of various development plans and policies on society, the economy, and the environment, enabling more sustainable and responsible choices. A comprehensive understanding of land use and land-cover patterns is essential for further research on sustainable resource management and climate change mitigation. While LULC research has advanced significantly, several critical questions require further investigation.

***Keywords*— Peatland; LULC; Bengkalis Regency; QGIS; FLEG.**

Manuscript received 18 Dec. 2023; revised 3 Feb. 2024; accepted 14 Apr. 2024. Date of publication 31 Jan. 2025.

I. INTRODUCTION

According to the Ministry of Environment, peat is soil formed from organic matter accumulation by producing biomass from tropical rainforests [1]. The Ministry of Agriculture defines peat as soil formed from the accumulation of organic matter with a composition of more than 65% that is formed naturally over hundreds of years from the decomposition of vegetation that grows on it, the decomposition process of which is inhibited by anaerobic and wet conditions [2]. The Ministry of Forestry further defines peat as a tree formation that grows in an area primarily formed by the accumulation of organic remains over a long period [3]. Land cover refers to the physical composition of the Earth's surface, encompassing elements like vegetation, bodies of water, soil, and various natural characteristics. It is subject to alterations due to human actions like urban development. Conversely, land use pertains to how humans utilize land for various objectives, predominantly those related to economic activities [4].

The recent peatland fires in Indonesia have resulted in substantial global environmental impacts. Nevertheless, the weather conditions for these fires are not yet fully understood. analysis of fires, precipitation, temperature, humidity, and wind in fire-prone areas in Sumatra [5]. Fires in tropical peatland forests are an environmental problem that climate change and deforestation affect. The consequences of these fires have both local and global implications. While research has shown that climate change is expected to make fires more severe and frequent, conflicting data from models and observations exist about the effect of deforestation on precipitation, which is a key factor in fire risk.

To better understand how deforestation and climate change affect fire risk [6]. Peatland forest fires are difficult to extinguish because they spread slowly underground and can last for days. This makes them difficult to detect and control, and they can release a large amount of CO2 into the atmosphere, as well as tropical peatlands, which are natural areas that are very important for the environment. They play a key role in regulating the climate by storing carbon dioxide, a greenhouse gas contributing to climate change. Peatlands also provide other significant environmental benefits, such as filtering water and preventing flooding[7], El Niño and peatlands are essential factors to consider when modeling fire in tropical forests.[8], In late 2015, El Niño and the Indian Ocean Dipole caused severe drought in Sumatra and Kalimantan, leading to massive fires and hazardous smoke pollution across much of Southeast Asia[9]. Fires frequently rage in Riau, an Indonesian province, causing haze disasters. Extinguishing these fires is challenging due to the abundance of peatlands in the burned areas. The government, community, and private sector are working together to address this disaster[10]. Land-use and cover change (LUCC) is a significant cause of environmental change, especially in tropical regions. This review summarizes recent estimates of changes in cropland, agricultural intensification, tropical deforestation, pasture expansion, and urbanization in tropical areas. It also identifies the land-cover modifications that have not yet been measured.

Based on this review, the authors propose a framework for a more comprehensive understanding of LUCC in tropical regions [11]. Next, the characteristics of the prolonged dry season of ENSO El Nino [12]. The Riau Provincial Government and the national and international community are concerned about the forest and peatland fires in Riau, which have caused a haze disaster in several Asian countries. One way to prevent these fires is to understand the potential fire points, how the fires spread, and the leading causes of the fires. One way to mitigate the fire risk in fire-prone areas is to add water reservoirs and canals. This would provide a source of water to extinguish fires and help to prevent them from spreading, according to analysis with GIS [13], [14], QGIS, a free and open-source desktop geographic information system (GIS) software, can be used to create, edit, visualize, analyze, and publish geospatial information [15].

A spatial modeling method can determine the geographic distribution of the factors that affect this phenomenon. The dynamic nature of this phenomenon can be predicted using spatial modeling and geographic information system (GIS) [16]. GIS analysis was employed to process spatial data by layering a land cover map over spatial policy data from various sources, sectors, and scales. This method, commonly known as Boolean Overlay (overlay), is a straightforward technique for combining spatial data in GIS. A new data layer is created with unique spatial units that incorporate combined attributes from the data sources[17]. Overlay is a powerful GIS tool that allows users to combine multiple map layers to create new information. It is a simple process of placing one map layer on top of another and displaying the results. Overlay can be used to identify spatial patterns and relationships that would be difficult to see on individual map layers [15]. While previous studies have used GIS models to investigate land use change, this study uses a digital change detection model and geo-referenced multi-temporal remote sensing data to analyze how land use patterns vary over time and space [19], [20]. Overlay techniques and QGIS are some of the software that can be used to implement overlay techniques in spatial data analysis. In QGIS, you can import data layers from various sources and use various overlays to merge or combine the data according to the needs of geographical analysis [21], [22].

The research on Pakhal Lake in India's Peninsular region underscores the considerable influence of dynamic processes, including environmental, economic, and social factors, on the fluctuations in land use and land cover (LULC) [23]. Rangsang Island, one of the primary islands in the peatland-dominated Kepulauan Meranti district, confronts substantial land utilization pressures near the Straits of Malacca. Given the hydrological intricacies associated with peatlands, characterized by periodic or continuous water saturation, this research focuses on deciphering the hydrological features of Rangsang Island's peatlands. By employing spatial and hydrological analyses, the study aims to provide valuable insights into the sustainable management of peatlands in the region [24].

From 2016 onwards, Central Kalimantan province has been enacting peatland restoration policies under the guidance of the Peat Restoration Agency (Badan Restorasi Gambut [BRG]) to address concerns such as peat subsidence, greenhouse gas emissions, and fire susceptibility. Despite dedicated efforts, the continued occurrence of local peat fires underscores persistent challenges and unexplored opportunities in the restoration process[25]. Peatland fires, an annual occurrence on Bengkalis Island, are often linked to incorrect land management practices. The scarcity of research exploring the connection between peatland fires and land management highlights the importance of establishing evidence-based models to reduce the prevalence of such incidents.

This research seeks to advance the understanding of peatland fire dynamics and proposes comprehensive management approaches for their mitigation[26]. Topographical maps, characterized by contour lines indicating land elevation relative to Mean Sea Level, play a crucial role in spatial analysis. Leveraging precise land survey data, the Quantum Geographic Information System (QGIS) software enables the construction of three-dimensional models, offering a more dynamic visualization of map objects compared to their real-world counterparts. This research utilizes QGIS for three-dimensional land contour modeling in Buwit Village, Kediri District, Tabanan Regency, Bali, enhancing the interpretability of the topographic map for more accessible analysis[27].

The investigation at hand thoroughly examines the spatio-temporal dynamics of Land Use Land Cover (LULC) types in Ranipet Municipal town, Ranipet District, Tamil Nadu State, India. Utilizing both QGIS and IDRISI Selva v.17.0 platforms, the study considers crucial parameters driving net changes in LULC types. Notably, the results highlight a substantial 26.8% positive net change in the built-up area, with vegetation, barren land, and water bodies experiencing net negative changes from 1997 to 2019[28]. The analysis of land use/land cover (LULC) changes is vital for gauging natural resource degradation within defined time periods. The integration of remote sensing and GIS techniques has demonstrated remarkable efficiency in mapping and analyzing LULC changes [29].

Contemporary research changes utilizing generated maps employs the CLUE-S LULC change model within a GIS framework to forecast future scenarios. Considering five scenarios and nine driving forces, the model forecasts a 5% expansion in built-up areas and a 6.5% reduction in agricultural areas from 2010 to 2018. Land use and land cover changes are influenced by natural processes and human activities within ecosystems[30]. During the period from 2005 to 2010, the examination of factors such as the Digital Elevation Model (DEM), distance from roads and rivers, human population dynamics, and built-up density identified noteworthy influences on the changes in land use and land cover (LULC) [31]. Studies addressing urban climate change consistently underscore the significance of anthropogenic Land Use and Land Cover (LULC) changes in shaping precipitation dynamics within megacities[32].

Recent research takes a quantitative approach to analyze the impact of urban growth on precipitation patterns in Shanghai, China, scrutinizing LULC data spanning 1979, 1990, 2000, and 2010 in conjunction with the long-term trend (1979–2010) of daily precipitation[33].The intricate relationship between urban growth and land use and cover change serves as the core of this study, aiming to quantify the effects of urban expansion along the outer ring road. Utilizing Remote Sensing and GIS, the analysis focuses on four segments—Chikkarayapuram, Nazarathpettai, Meppur, and Perungalathur—examining 2009, 2012, and 2016 land cover maps. Changes across seven classes, including agriculture, barren land, residential units, industry, water bodies, other vegetation, and marshland, are assessed regarding spatiotemporal aspects, environmental impacts, and economic factors [34].

The purpose of the study is to map the existing conditions of peatland cover and land use in Bengkalis Regency; analyze the relationship between physiographic factors, peat physical characteristics, climate, and human activities with peatland fires in Bengkalis Regency; formulate a peatland fire prevention strategy. Several problem-solving approaches used to achieve the objectives are the overlay method (overlay) against various digital maps related to administrative boundary, distribution of peat depth and decomposition, land cover and use, status of peatland ecosystem function, to the status of existing land management.

II. Materials and Method

The research was conducted in the administrative area of Bengkalis Regency, Riau Province, as shown in Figure 1. Geographically, the regency is located on the east coast of Sumatra Island, covering an area of 7,773.93 km^2. There are two large islands in the regency, namely Rupat Island, with an area of 1,524.83 km2, and Bengkalis Island, with an area of 938.40 km2. Administratively, before 2017, there were only eight sub-districts in Bengkalis Regency. However, with the inauguration of three new sub-districts on February 9, 2017, which had also been established based on the Bengkalis Regency Regulation No. 6 of 2015, the number of sub-districts changed to 11. The three new sub-districts are BathinSolapan District, which was split from Mandau District; Bandar Laksamana District, which was split from Bukit Batu District; and TalangMuandau District, which was split from Pinggir District. Situated near Malaysia and Singapore, Bengkalis Regency remains at the forefront of efforts to implement the ASEAN Agreement on Transboundary Haze Pollution (AATHP), ratified by Indonesia through Law No. 26/2014.

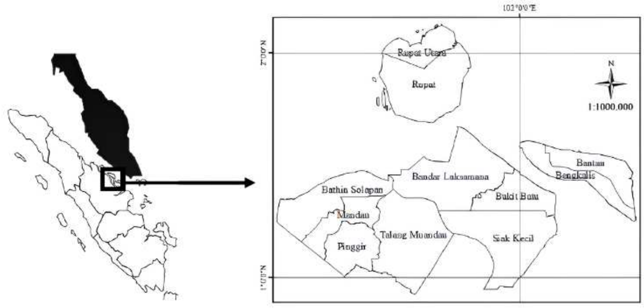

Fig. 1 Bengkalis Regency, source BIG

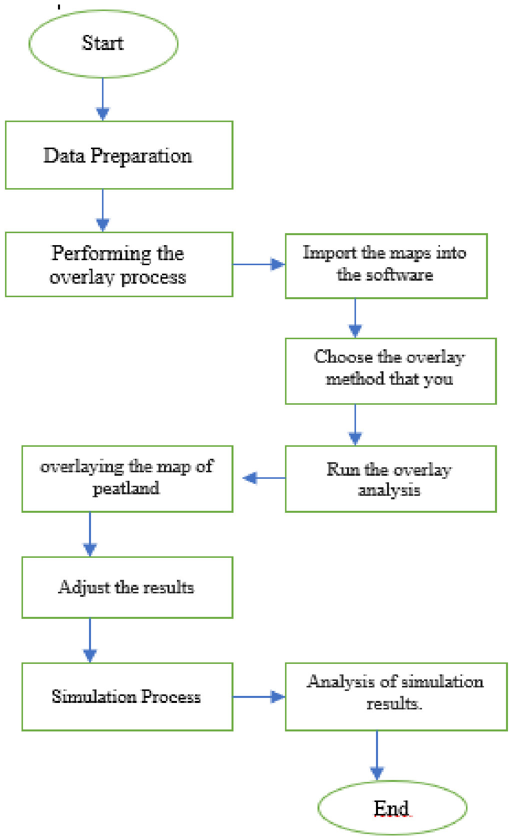

Fig. 2 Simulation With QGIS LULC

The data collected in this study are various maps, including:

a. Map of the administrative boundaries of Bengkalis District in 2018 from the National Geospatial Information Agency (BIG)
b. Map of land cover and use extracted from the Rupa Bumi (RBI) map in 2018 from the National Geospatial Information (BIG) classified according to SNI 7645
c. Map of natural/river drainage networks extracted from RBI map in 2018 from BIG
d. Map of artificial/canal drainage networks extracted from RBI map in 2018 from BIG
e. Map of road networks extracted from map in 2018 from BIG covering arterial roads, local roads, and other roads
f. Map of the National Peatland Ecosystem Function that has been established based on SK Ministry LHK No.

130 2017 from the Directorate General of Forest Planning and Environmental Management, Ministry of Environment and Forestry.

g. Map of peatland distribution from the Ministry of Agriculture in 2017.
h. Map of the depth and type of peat decomposition extracted from the Map of the Distribution of Peatland from Wetlands International Indonesia (WII)
i. Map of plantation and planted forest concessions in 2023 from Global Forest Watch-World Resources Institute (GFW-WRI).

The steps for simulation are:

a. (Phase 1). Data preparation(Map of the administrative boundaries of Bengkalis District, land cover and use extracted from the Rupa Bumi (RBI), and natural/river drainage networks extracted.
b. (Phase2). overlay process:
c. To perform overlay analysis, first, import the maps into the software, select the layers to overlay, determine the overlay method to be used for combining these layers. After all the above steps are completed, conduct the overlay analysis to see the results of the combined data from the layers selected
d. (Phase 3) Map of the distribution of peatlands against administrative boundaries: this map shows the location of peatlands in Bengkalis District, concerning the administrative boundaries of the district. The map is created by overlaying the map of peatland distribution with the map of administrative boundaries (a).
e. (Phase 4) Map of the distribution of peatlands against administrative boundaries: this map shows the location of peatlands in Bengkalis District, regarding the administrative boundaries of the district. The map is created by overlaying the map of peatland distribution with the map of administrative boundaries (b). Adjust the results with SK Minister LHK No. 130 in 2017. The results of the map of peatland distribution are adjusted with the provisions of SK Minister LHK No. 130 in 2017.[35].For defines the criteria to determining the boundaries of peatlands. Adjustments are made to ensure the resulting map. The results obtained consist of maps of rivers, canals, roads, peatlands, and protected areas. Then, the results of the digitized data are adjusted with the peatland distribution map and can be used to identify and map areas with potential conflicts between concessions and areas that need protection, such as peatlands and protected areas.
f. This phase involves using specific colours to represent different features on the map for **Peatlands**: Solid green, **Roads**: Solid red, **Protected Areas**: Solid yellow and **Concessions**: Solid black, the next phase analysis of the result.

III. Results and Discussion

A. Data Analysis

This research involves overlaying data or maps collected to obtain an overview of the existing condition of peatland cover and land use in Bengkalis Regency. The software used for this stage is QGIS 3.3.21 for spatial data analysis [36]. This involved overlaying the maps of peat depth and decomposition type from WII. the peatland distribution map from the Ministry of Agriculture, and the National Peat Ecosystem Function map designated based on the Minister of Environment and Forestry Decree No. 130 of 2017[35] in Bengkalis Regency covers 5,047.779km2 or 504,777,91hectares. This area accounts for 61.38% of the total administrative area of Bengkalis Regency.

TABLE I
THE COMPARISON OF THE ADMINISTRATIVE AREA SIZE WITH THE PEATLAND AREA SIZE

No.	SubDistrict	Area Size (Ha)	Area Size of Peatland (Ha)
1	Bantan	31,596.03	27,990.81
2	Bengkalis	58,952.14	53,305.50
3	Bukitbatu	203,686.53	172,858.13
4	Mandau	116,656.62	37,159.71
5	Pinggir	194,702.85	76,239.67
6	Rupat	107,473.30	67,817.63
7	Rupat Utara	42,953.29	11,846.17
8	Siakkecil	66,421.73	57,560.29
	Total	**822,442.50**	**504,777.91**

Table I shows that the largest peatland area in Bengkalis Regency is located in Bukit Batu District. However, the district with the highest percentage of its area covered by peatlands is Bengkalis District, where 90.42% of the district's administrative area is covered by peatlands. The map of peatland distribution in Bengkalis Regency can be seen in Figure 2 below,

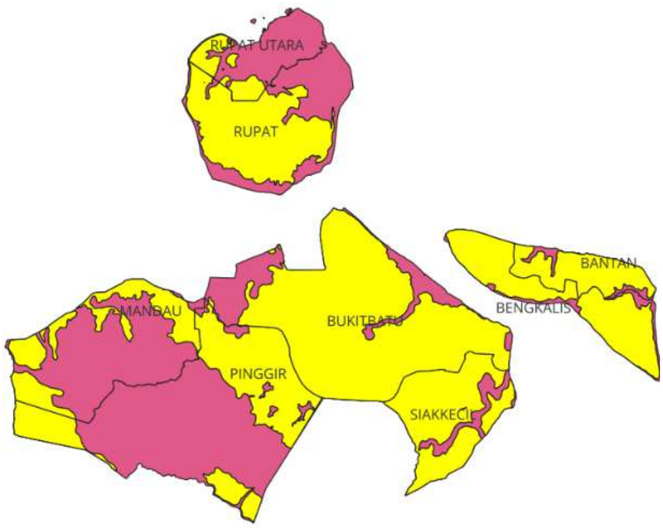

Fig. 3 The map of peatland distribution in Bengkalis Regency

Figure 3 above shows that peatland is most extensively distributed in the regions of Rupat, Bantan, Bengkalis, Bukit Batu, and Siakkecil, marked in yellow. According to the WII data, there are six peat depth categories: very shallow, shallow, moderate, deep, and mineral soil. Additionally, the peat types consist of Hemik, Sapric, Fibric, Mineral, and combinations of these four types. Subsequently, we digitized the peat depth and decomposition type maps from WII to obtain the decomposition types and depths of peat in the Bengkalis Regency.

In Figure 4, it is evident that plantation land (in red) and natural forest (in blue) dominate the land use in the peatland areas of Bengkalis Regency. The substantial proportion of plantation land identifies the sector's significant role in the development and economy of the Bengkalis Regency. The plantation sector's significant contribution to the economy is unsurprising, as it is intrinsically linked to the region's inherent potential. Additionally, Bengkalis flat topography and strategic position near international markets, both geographically and economically, have facilitated land clearing activities. This inevitably intertwines regional development policies with the expansion of the plantation sector, including the cultivation area's expansion, be it through smallholder systems or by creating opportunities for the private sector. Given these circumstances, it would be advisable for the government to promptly formulate and clarify programs governing land replacement to replace plantation and timber plantation areas, as mandated by PP No. 71 of 2014 in conjunction with PP No. 57 of 2016[37], which necessitate restoration. This is intended to reduce friction between the central government and the regions.

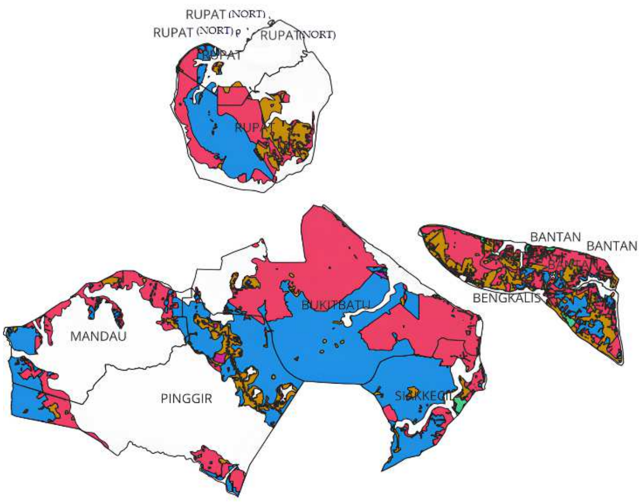

Fig. 4 Peatland land cover and land use in the Bengkalis Regency

B. Concession Areas in Peat Ecosystems

Based on the provisions in PP No. 71 of 2014 in conjunction with PP No. 57 of 2016, in Article 9 paragraph 3,[37] the Ministry of Environment and Forestry (KLHK) established the National Peat Ecosystem Function map on February 27, 2017. On this map, the identified peat ecosystems are divided into two categories: cultivation and protection functions. This classification serves as a reference for developing and determining the National Peat Ecosystem Protection and Management Plan.

To gather information related to cultivation/concession activities, whether for timber plantations or oil palm, an overlay was conducted between the 2017 peat ecosystem function from KLHK and the oil palm and timber plantation concession maps obtained from Global Forest Watch-World Resources Institute (GFW-WRI) in 2023[38]. As presented in Figure 4, the results of overlaying these maps reveal that in the Bengkalis Regency, there is a minimum of 175,081.19 hectares of concession areas located within the Peat Ecosystem Protection Function (FLEG)

Figure 5 shows that the protective function of peatlands in the Bengkalis Regency area is that many are used to create plantation or plantation forest locations (oil palm plantation concessions and industrial plantation forests cover the green color). Even though the government has stated that it still gives companies/concession permit holders under FLEG the opportunity to continue business cultivation activities for the remainder of the crop cycle until the land restoration period, However, it cannot be denied that violations of cultivation activities in FLEG will trigger economic contraction in the Bengkalis Regency area. A detailed picture of the density of the road and drainage network that has been built in the peat ecosystem in the Bengkalis Regency area is presented in Figure 5, which is produced from the overlapping process between the national peat ecosystem map from the Ministry of Environment and Forestry with the road network map and drainage from BIG.

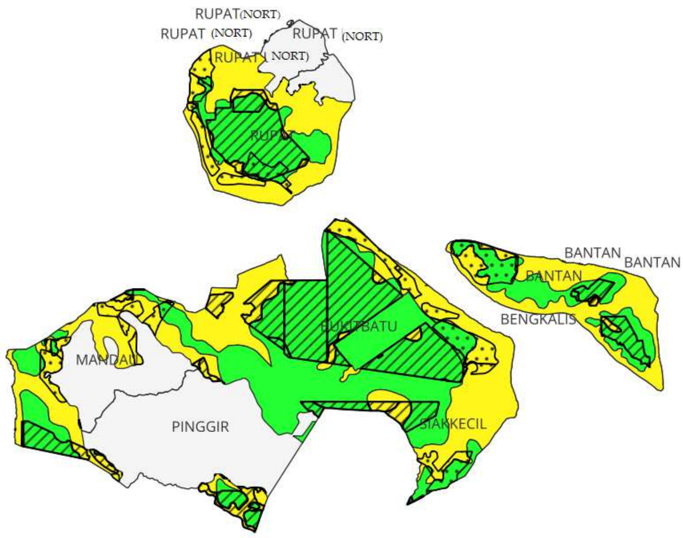

Fig. 5 Map of peat land concessions in the Bengkalis Regency area

Almost all peatlands in the Bengkalis Regency area have experienced the construction of road and drainage networks. Furthermore, Table II provides data on the length and density of roads and drainage.

TABLE II
LENGTH OF ROAD AND DRAINAGE NETWORK IN PEAT ECOSYSTEMS IN BENGKALIS REGENCY

No.	Subdistricts	Peat Hydrological Unit (PHU)	Length of each peat ecosystem function (Km)			
			Protection Function		Cultivation Function	
			Road	Drainage	Road	Drainage
1	Bantan	PHU of Bengkalis Island	166,3968	37,51089	478,1471	91,92059
2	Bengkalis	PHU of Bengkalis Island	288,9167	195,9139	475,1241	138,1089
3	Bukitbatu	PHU of Rokan River - Siakkecil River	706,4633	1470,465	889,6082	401,6853
4	Mandau	PHU of Rokan River - Siakkecil River	273,8474	37,70591	982,5695	85,83522
		PHU of Rokan River - Mandau River	92,39185	6,021235	230,6342	51,17181
5	Pinggir	PHU of Bunut River - Umban River	85,66916	74,54497	66,06809	25,57367

Table III below explains the classification of peatland cover and use in the Bengkalis Regency area. Classification of Pearland cover and use (Lake, Fishing Pond, mangrove, jungle, plantation, place activity, rice field, river, farm the total area (Ha): 504,590.8. The largest sub-district is

Bukitbatu with an area of 172,857.9 for classification of peat land cover and use. where the function of Classification of peatland cover and use is to provide essential data for peatland management. Peatland cover and classification data can be used to determine the current condition of peatlands. This data is very important for sustainable planning and management of peatlands, it can be used to monitor changes in peatland cover and use over time. This data can be used to evaluate the impact of various activities carried out on peatlands, such as plantations, mining and fires. determine the potential of peatlands for various uses, such as agriculture, plantations and conservation. This data can be used to formulate policies and strategies for optimal peatland use. Classification of peat land cover and use for Rupat Nort 11,846.2 Ha, which is the smallest area compared to other sub-districts.

TABLE III
CLASSIFICATION OF PEAT LAND COVER AND USE IN THE BENGKALIS REGENCY AREA

No.	Classification of peatland cover and use	Subdistricts								
		Bantan	Bengkalis	Bukitbatu	Mandau	Pinggir	Rupat	North Rupat	Siakkecil	Total
1	Lake			10.0		2,180.0				2,190.0
2	Fishing Pond	7.6	9,2	3.8	1,1					21.7
3	Mangroves			.				34,9		34.9
4	Jungle	2,210.0	8,590.8	72,585.1	14,221.8	46,485.1	27,782.7	3,155.7	40,353.1	215,384.2
5	Plantation	17,297.0	22,137.2	96,460.3	20,.653.8	12,982.0	26,695.8	7,462.0	13,195.3	216,883.3
6	Settlements and Places of Activity	1,371.7	1,709.7	165.5	25,5		8.5		294.3	3.575,3
7	Rice field		42.0							42.0
8	Shrubs	6,388.2	19,187.6	3,050.8	2,224.1	14,240.7	13,330.3	1,185.7	2,392.0	61,999.6
9	River	4,1	10.2	3.7		203.5		1.6	31.5	254.5
10	Pond	2.0	28.4							30.3
11	Empty / Bare Land			499.7	25,9	116.1			273.1	914.,8
12	Moor / Farm	529.8	1,587.2	79.1	6,5	31.1		6.2	1,020.3	3,260.2
	Total area (Ha)	**27,810.3**	**53,302.3**	**172,857.9**	**37,158.7**	**76,238.5**	**67,817.4**	**11,846.2**	**57,559.6**	504,590.8

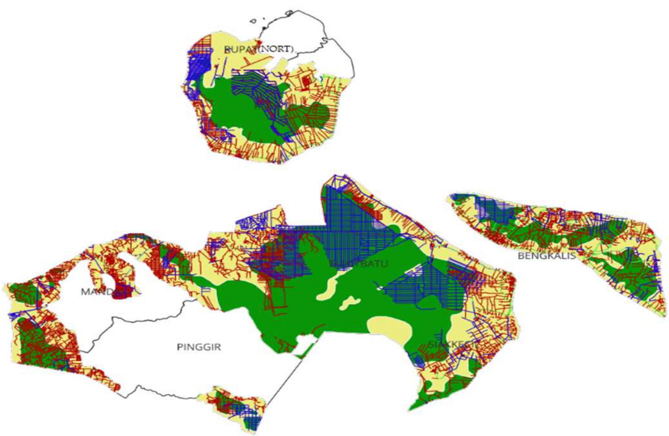

Fig. 6 Map of the road and drainage network in the Bengkalis Regency area

In Figure 6, it is evident that almost the entire peatland in the Bengkalis Regency has undergone the construction of road and drainage networks. It is known that nearly all of the Peat Ecosystem Functions (FLEG) in the Bengkalis Regency have dense road and drainage network development, especially in areas like Rupat island (Rupat and South Rupat sub-districts), Bengkalis (Bantan and Bengkalis sub-districts), Rokan island – SiakKecil island (BathinSolapan, Bandar Laksamana, Mandau, and Bukit Batu sub-districts), Rokan river - Mandau river (Mandau and side sub-districts), and SiakKecilriver(TalangMuandau sub-district). Looking at the density of the built road and canal infrastructure, questions arise regarding the government's preparedness, especially the local Regional Apparatus Organization (OPD), in ensuring the availability of budget and human resources (HR) needed for supervision and maintenance. This is crucial given that, with the implementation of PP No. 71 of 2014 in conjunction with PP No. 57 of 2016[37], the operational activities of companies in concessions falling under the FLEG category will significantly decrease. Without the financial support and the necessary human resources for supervision and maintenance that was initially the company's responsibility, the built infrastructure (e.g., road and canal networks) will likely deteriorate and become damaged. In the long term, the deterioration of this established infrastructure can increase the vulnerability to peatland ecosystem damage.

IV. CONCLUSION

In Bengkalis Regency, an examination of the connection between physiographic factors and the physical attributes of peat, climate, and human activities within peatland areas, particularly concerning peat forest and land fires, led to the development of a preventative strategy for addressing peat forest and land fires in Bengkalis Regency. The analysis approach employed to achieve the specified objectives involves using an overlay method. This research shows that twelve types of land use and land cover (LULC) have been identified in Bengkalis Regency's peatlands. These include plantations (42.98%), primary forests (42.68%), shrubs (12.29%), residential and activity areas (0.71%), fields (0.64%), lakes and ponds (0.43%), empty or bare land (0.18%), rivers (0.05%), and various other features like ponds, mangrove forests, and rice fields, each ranging from 0.004% to 0.008%. Additionally, within the Peat Ecosystem Protection Function (FLEG), there are at least 175,081.19 hectares of concession areas in the Bengkalis Regency. Understanding these land use and cover patterns comprehensively is crucial for sustainable resource management and effective climate change mitigation strategies in future research.

ACKNOWLEDGMENT

The Directorate of Research, Technology, and Community Service of the Ministry of Education, Culture, Research, and Technology funds this research.

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