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Clustering and Significance in Spatial Distribution Analysis of the Skudai River Catchment Using Geographic Information System (GIS)

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Abstract: In this study, the spatial distribution patterns of point source pollution in the upstream Skudai River catchment were investigated, focusing on restaurants, laundromats, car washes, and workshops. Rapid urbanization and industrialization in the region have led to environmental challenges, including changes in hydrology, geomorphology, and deterioration in water quality. GIS technology played a crucial role in analyzing and visualizing the spatial dynamics of point source pollution. The analysis revealed non-random clustering patterns for each pollution source category, with concentrations observed in specific areas within the catchment. The study also explored the correlation between point source pollution and land use types, identifying concentration hotspots in commercial and residential areas, with the transportation sector emerging as a significant contributor to pollution. The proximity of pollution sources to water bodies and neighbor pattern analysis provided further insights. The findings offer valuable information for water resource management, environmental conservation, and urban planning in the Skudai River catchment, highlighting the importance of GIS-based spatial analyses for informed decision-making and effective pollution control measures.

Keywords: Spatial distribution; pollution; GIS, environmental; land use

1.0 Introduction

Rapid urbanization and industrialization often bring about increased environmental challenges, with point source pollution emerging as a critical concern. Rapid urbanization has caused serious issues such as environmental pollution, land use transformation, flash floods, and disruption of the river ecosystem (Khayrullin et al., 2023). Uncontrolled rural-to-urban migration, driven by the pursuit of better opportunities, has led to unprecedented urbanization in the river basin, resulting in significant negative impacts on the health of the river system, including alterations in hydrology, geomorphology, and water quality deterioration (Shukla et al., 2013). Effective management of point source pollution is essential to safeguard water quality, ecosystems, and public health. Point source pollution, originating from sewage treatment plants, commercial areas, and industrial discharges, poses a significant threat to the regional environment, impairing aquatic ecosystems and potentially affecting human health and socioeconomic conditions (Yao et al., 2015).

Point source pollution refers to the release of pollutants into the environment from identifiable and localized sources, often defined by specific geographic coordinates (Braden & Shortle, 2013). This study focuses on the spatial distribution of four distinct point source pollutants—restaurants, laundromats, car washes, and workshops—in the upstream region of the Skudai River catchment using GIS. GIS technology allows for the analysis and visualization of spatial data, providing valuable insights into the distribution patterns of various phenomena (Ariffin et al., 2023; Zhou & Li, 2021). It enables researchers to determine the spatial extent, center of gravity, and helps in understanding their distribution patterns. GIS-based analysis facilitates the identification of trends, patterns, and relationships in spatial data, which is crucial for effective urban planning, resource allocation, and decision-making.

The Skudai River catchment area holds particular significance as it serves as the source of water for the Sultan Ismail Water Intake, making it imperative to understand the spatial dynamics of point source pollution for effective water resource management and environmental conservation. According to Sarijan et al. (2018), it is reported as the most populated river in Peninsular Malaysia, with a significant amount of rubbish found in the river. The relationship between point source pollution and land use types plays a pivotal role in shaping the environmental impact within the Skudai River catchment. Land-use conflicts and poor land-use management can have a substantial impact on watershed management, resulting in detrimental consequences for water supplies, flooding, and environmental pollution. Inefficient utilization and management of land can lead to conflicts arising from competing interests and land uses, thus worsening the challenges involved in sustainable catchment management (Stosch et al., 2022). Various land use categories, including residential, commercial, institutional, and industrial, contribute to the diverse mosaic of the landscape. Analyzing how different point source pollutants are distributed across these land use types provides insights into potential pollution hotspots, aiding in the formulation of targeted regulatory measures and land use planning strategies.

Furthermore, the proximity of point source pollution to water bodies is a crucial aspect of this study. Given the Skudai River catchment's role as a water source, investigating how pollutants are distributed in relation to the distance from the river is essential. The distance of pollution sources to water resources has a significant impact on water quality (Fernandes et al., 2019). This analysis can help identify potential sources of contamination and better understand the spatial patterns of pollution in relation to the river network. In addition to land use and distance to the river, exploring the neighbor patterns of point source pollution is integral to understanding the localized clustering or dispersion of pollutants. The spatial arrangement of pollution sources, as determined by average nearest neighbor analysis, provides valuable insights into the potential interactions and cumulative effects of these sources, aiding in the development of targeted pollution mitigation strategies. Overall, this multi-faceted study aims to enhance our understanding of the spatial distribution of point source pollution in the Skudai River catchment, contributing to more informed and effective environmental management practices.

2.0 Study Area

The Skudai River Catchment is located within two districts in Johor, specifically Kulai and Johor Bahru. It is demarcated by latitudes 1° 44' 00'' and longitudes 103° 40' 00''. This catchment is situated in the state of Johor, which is well-known for its diverse topography, encompassing urban areas, agricultural fields, and nature reserves. Within this region, the Skudai River, a prominent waterway in the catchment area, flows through and ultimately empties into the Johor Strait. The catchment area consists of a variety of land uses, including urban and industrial zones, agricultural regions, and natural habitats. The Skudai River catchment encompasses five primary rivers: the Skudai River (the main river), as well as Sungai Sengkang, Sungai Senai, Sungai Melana, and Sungai Danga. According to the Department of Environment (DOE), two rivers in this catchment, Skudai and Melana, are slightly polluted (Naubi et al., 2017). The catchment is also prone to flooding,

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especially during the monsoon season. The average annual precipitation within the watershed is 2,396 mm, as recorded in a climate dataset observed over a span of 30 years (Bello & Haniffah Mohd, 2021).

The catchment area of the Skudai River encompasses a land mass of approximately 293.3 square kilometers, while the main river itself stretches for approximately 46 kilometers. However, the focus of this particular study revolves around the water quality at the Sultan Ismail Water Treatment Plant (SIWTP). Consequently, the study area is restricted to the region upstream of the SIWTP, which spans around 136 square kilometers, or 46% of the entire Skudai River catchment. The river flows in a south-eastern direction, traversing various urban areas such as Kulai, Saleng, Skudai, Tampoi, and ultimately terminating at the Straits of Johor. According to the Iskandar Regional Authority's 2011 report, it is anticipated that urban areas will occupy 80% of the catchment area in the future. This urbanization will consist of approximately 62% residential areas, 27% commercial areas, 2.6% industrial areas, and 8.4% roads and utilities (IRDA, 2011). The topography of the basin is generally characterized by undulating terrain, with the steepest slope ranging from 25 to 40 degrees, which encompasses only a small portion of the basin in the western section of the Sg Senai Sub-basin. Figure 1 provides a visual representation of the upstream Skudai River catchment, the boundary of the study area, and the precise location of the SIWTP.

Figure 1: Study area map.

3.0 Materials and Methodology

3.1 Materials

"This study used ArcGIS 10.8 for analysis, geodatabase management, data conversion, GIS analysis, and point source pollution mapping. Utilizing GIS for spatial distribution analysis in the Skudai River catchment involves integrating various geospatial datasets obtained from diverse sources (Ramli et al., 2024). The data used in this study comprise point source pollution information for restaurants, launderette marts, car washes, and workshops, as well as land use information, river networks, and catchment boundaries. Each dataset is formatted differently, reflecting the nature of the information and the source from which it was collected. The point source pollution data for restaurants, launderette marts, car washes, and workshops are available in Keyhole Markup Language (KML) format, sourced from Google Earth. All point source locations were digitized using Google Earth Pro imagery collected in January 2023.

To validate the accuracy of the digitized KML data, a ground-truthing exercise was carried out at selected sites within the study area. Approximately 85% of the point source locations were physically visited and confirmed. Google Earth was selected as a source for extracting point source pollution data due to its high-resolution satellite imagery and the availability of location tags for commercial entities. The use of KML data allowed for the efficient identification and digitization of locations such as restaurants, workshops, and car washes that are visually distinguishable from imagery and/or labeled by user-contributed metadata (Ramli et al., 2024).

The land use data, crucial for understanding the contextual relationship between point source pollution and the surrounding environment, is provided in Shapefile format. This information originates from the Kulai Local Authority, offering a detailed classification of land use types such as residential, commercial, industrial, and more. The river network, represented in Shapefile format, is sourced from Earth Data. This dataset delineates the spatial extent and connectivity of rivers within the Skudai River catchment. Understanding the proximity of point source pollution to these water bodies is fundamental for assessing potential environmental impacts and developing targeted pollution control measures. The catchment boundary data, also in Shapefile format and obtained from Earth Data, demarcates the geographical limits of the Skudai River catchment. This dataset serves as the spatial framework for the entire study, allowing for the confinement of analyses within the specific geographic area of interest. Table 1 presents the dataset utilized in this study, detailing the format and sources of each data category.

Table 1: List of data

Data	Format	Source	Year
Restaurant	KML	Google Earth	2023
Launderette mart	KML	Google Earth	2023
Car wash	KML	Google Earth	2023
Workshop	KML	Google Earth	2023
Land use	Shapefile	Kulai Local Authority	2022
River	Shapefile	Earth Data	2022
Catchment Boudary	Shapefile	Earth Data	2022

The examination conducted in this investigation utilized ArcGIS 10.8 software. To begin, the extracted point source pollution data from Google Earth was converted into shapefile format. Subsequently, all GIS data (including point source pollution data, river network, catchment area, and land use) was stored in the GIS database prior to conducting the analysis. Three types of analysis were employed to achieve the objectives of this investigation. The first analysis involved a buffer analysis of the distance between the point source pollution locations and the main river, the Skudai River. The buffer analysis was performed at four distinct distances: 0 to 0.5 kilometers, more than 0.5 kilometers to one kilometer, more than one kilometer to two kilometers, and more than two kilometers to three kilometers. This analysis determined the number of point sources of pollution within each range.

The second analysis entailed an overlay analysis between the point source locations and land use data. This allowed the identification of the areas where pollution sources were concentrated and the types of land use associated with them. Finally, the third type of analysis employed in this study was average nearest neighbor analysis, which evaluates the distribution pattern of point-source pollution. Average nearest neighbor analysis has been proven to be valuable in various domains, including tourism, transportation, urban planning, and environmental planning (Odum et al., 2018). This analysis helps determine whether the distribution of pollution sources exhibits clustering, dispersion, or randomness. The primary objective is to measure the spatial configuration of characteristics by comparing the mean distance from each characteristic to its closest neighbor with the expected outcome under random distribution.

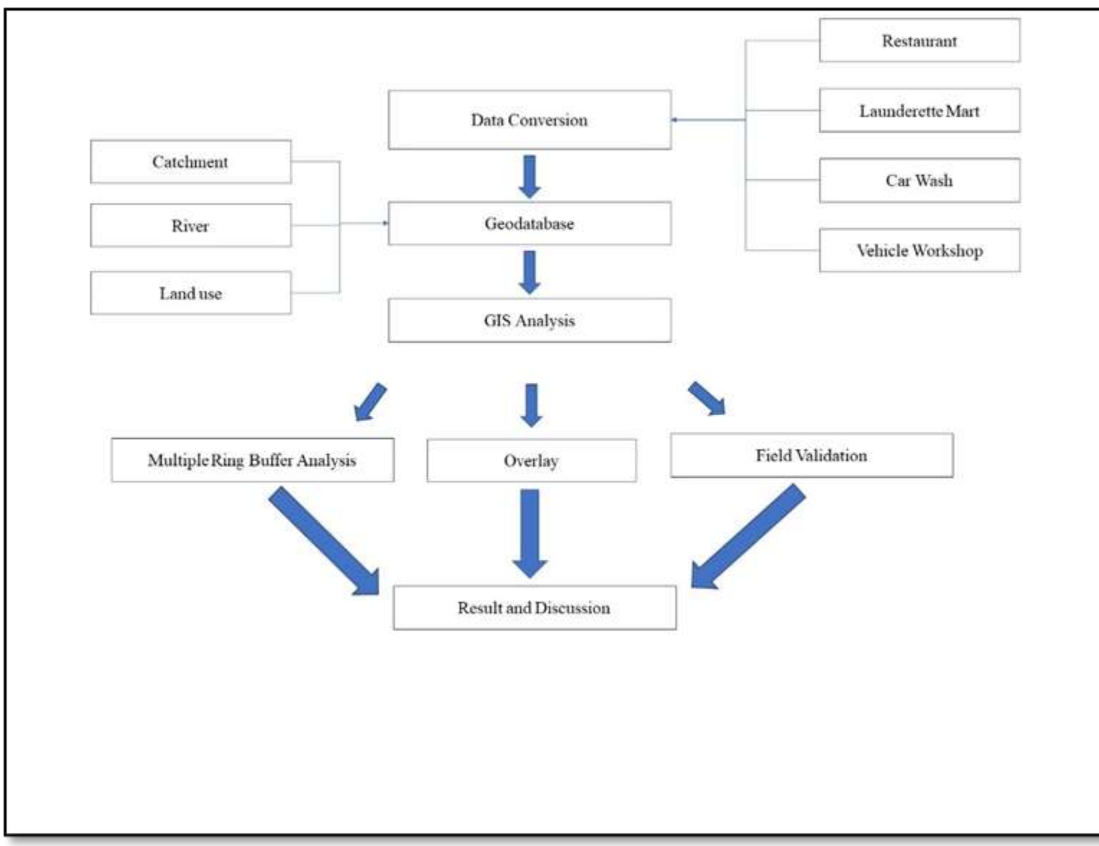

Figure 2: Methodology flow chart.

4.0 Results and Discussion

The analysis revealed distinct patterns in the distribution of point source pollution at different radial distances from the main river. For restaurants, the majority (150) were found within the 0 to 0.5 km buffer zone, with diminishing numbers observed as the distance increased: 161 between 0.5 km and 1 km, 50 between 1 km and 2 km, and only 12 beyond 2 km to 3 km. Restaurants typically release wastewater from cooking, dishwashing, and housekeeping activities, which may contain oil and grease (O&G), suspended solids (SS), and detergents, all of

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which can pollute nearby rivers (Yau et al., 2021). Launderette marts exhibited a different trend, with 11 located within the 0 to 0.5 km zone, 22 between 0.5 km and 1 km, 23 between 1 km and 2 km, and 6 beyond 2 km to 3 km.

The selection of buffer intervals ranging from 0.5 km to 3 km was informed by contemporary studies on pollutant transport in urban catchments. Research has shown that urban pollutants from point sources such as restaurants, laundromats, and workshops can travel significant distances via stormwater runoff and drainage networks, especially in areas with high impervious surface coverage and poor waste containment (Zoppou, 2001; Rai et al., 2023). The 3 km upper limit ensures the inclusion of indirect pollution effects and aligns with common distances used in similar watershed studies (Rashid et al., 2021; Liao et al., 2020). These intervals also help detect pollution gradients and are useful for spatial planning and risk mapping. The considerable release of wastewater from launderette marts has greatly burdened the municipality's sewage treatment system, resulting in severe pollution of water bodies (Liu et al., 2014). Car washes and workshops showed similar patterns, with higher concentrations near the main river, gradually decreasing with increasing distance. Table 2 presents the results of the multiple ring buffer analysis for each point source of pollution.

Table 2: Number of point pollution based on distance

Pollution type	Distance from main river				
	0 to 0.5km	More than 0.5km to 1km	More than 1km to 2km	More than 2km to 3km	Total
Restaurant	150	161	50	12	373
Launderette mart	11	22	23	6	62
Car wash	18	23	24	8	72
Workshop	24	37	12	7	80

The results from the multiple ring buffer analysis highlight the proximity-based distribution of point source pollution in the Skudai River catchment area. Restaurants, which are more numerous closer to the main river, may contribute to higher pollution levels in these regions. In contrast, laundromat marts, car washes, and workshops exhibit a more dispersed pattern, with substantial numbers located at varying distances from the river. This spatial information is crucial for informed decision-making in pollution control and environmental management, as it allows stakeholders to target specific areas for mitigation measures or regulatory interventions based on the concentration and distribution of pollution sources. Further analysis and integration of these results with other spatial datasets could enhance the understanding of the environmental impact of these point source pollutants on the Skudai River catchment area. Figure 3 presents the map of point source pollution at different distances from the Skudai River.

The overlay analysis revealed intricate patterns of point source pollution distribution across different land use types. Residential areas, for instance, demonstrated a significant concentration of restaurants (59) and a modest presence of car washes and workshops, suggesting potential localized environmental stress. Commercial zones exhibited the highest concentrations across all pollution categories, with restaurants (155) and workshops being particularly prominent. Institutional and public facilities displayed minimal pollution, highlighting the success of environmental regulations in these areas. Notably, the transportation sector emerged as a significant contributor to pollution, with high numbers of restaurants, car washes, and workshops present near transportation infrastructure. These findings underscore the need for targeted environmental management strategies, as specific land use types exhibit varying degrees of vulnerability to point source pollution. Understanding these spatial relationships is pivotal for sustainable development and informed decision-making, enabling policymakers to implement effective pollution control measures tailored to the diverse land use characteristics in the upstream Skudai River catchment. Table 3 displays the number of point source pollution based on different types of land use.

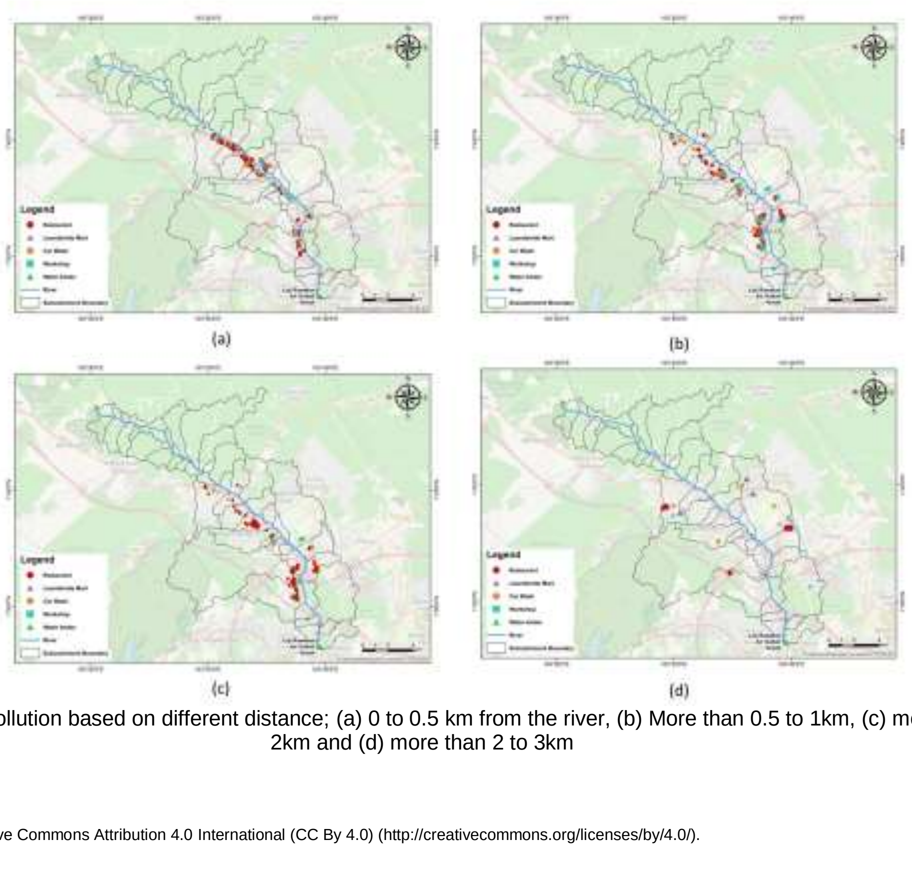

Figure 3: Point source pollution based on different distance; (a) 0 to 0.5 km from the river, (b) More than 0.5 to 1km, (c) more than 1.0km to 2km and (d) more than 2 to 3km

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The Average Nearest Neighbor analysis reveals significant clustering patterns for each pollution source category. Restaurants exhibit a highly clustered pattern, with a nearest neighbor ratio of 0.202 and a remarkably low z-score of -29.468, indicating a strong tendency towards spatial aggregation. Similarly, launderette marts and car washes also display clustered patterns, with nearest neighbor ratios of 0.340 and 0.5911, respectively. The z-scores of -9.949 and -6.683 for launderette marts and car washes, respectively, signify statistically significant clustering. Furthermore, the workshop category exhibits a nearest neighbor ratio of 0.396 and a z-score of -10.337, emphasizing a pronounced clustering pattern. The extremely low p-values (all less than 0.000001) across the pollution categories reinforce the statistical significance of the observed clustering.

Table 3: Number of point source pollution based on land use type

Land use Type	Restaurant	Launderette Mart	Car wash	Workshop
Residential	59	14	14	4
Commercial	155	28	21	33
Institutional and Public Facilities	2	0	0	2
Industry	6	0	1	10
Transportation	130	17	30	25
Vacant Land	9	0	1	2
Open spaces and Recreational	10	0	3	1
Infrastructure and Public facilities	2	2	0	0
Agriculture	0	1	2	3
Total	373	62	72	80

Among the analyzed point source categories, restaurants emerged as the main contributors to potential pollution, with a total of 372 locations and the greatest number of sources (150) within the 0–0.5 km buffer from the river. Workshops and vehicle washes pose significant environmental hazards due to the presence of grease, hydrocarbons, and heavy metals. The spatial study identified hotspots in commercial and mixed-use urban areas, where high-density land use overlaps with proximity to rivers. These clusters align with transportation corridors and urban commercial areas, where service-oriented businesses are densely located. The south-eastward flow of the Sungai Skudai promotes the downstream accumulation of pollutants. During the monsoon season, elevated surface runoff presumably transports pollutants from upstream sources, resulting in increased pollution loads at the Sultan Ismail Water Treatment Plant (SIWTP). These findings underscore the need for effective control actions to mitigate the cumulative downstream effects on water quality.

The spatial clustering of point source pollution, particularly in commercial areas, aligns with trends identified in urban catchments worldwide. Research conducted in cities such as Shanghai (Yu et al., 2022) and Dhaka (Rashid et al., 2021) indicated elevated pollutant levels in commercial areas, attributed to the high concentration of service-oriented enterprises, including restaurants and automotive workshops. These businesses commonly generate waste materials such as oil, grease, detergents, and chemical runoff, which significantly contribute to both non-point and point source pollution in neighbouring water bodies. The clustering observed in the Skudai River catchment can be linked to several fundamental processes. Zoning restrictions in urban areas often designate central, accessible locations for commercial operations, leading to spatial concentration. Additionally, economic clustering occurs when businesses group together to capitalize on shared infrastructure and client accessibility. Furthermore, insufficient enforcement of environmental regulations or inadequate wastewater treatment standards in certain areas may exacerbate contamination risk.

The localized context of this study provides specific findings compared to global trends. In rapidly urbanizing Malaysian cities, commercial development often outpaces environmental regulations, and localized planning frameworks may inadequately address proximity to water bodies. This study offers region-specific insights into the connection between urban growth patterns and water pollution, emphasizing the need for buffer restrictions, zoning reforms, and integrated land use–water quality planning.Figure 4 presents the results from the average nearest neighbor analysis for each pollution source. The findings underscore the non-random distribution of point source pollution within the upstream Skudai River catchment. The clustering patterns indicate that certain areas experience higher concentrations of pollution sources, potentially contributing to localized environmental stress. Understanding these spatial dynamics is crucial for implementing targeted pollution mitigation strategies. Additionally, the exceptionally low p-values and z-scores highlight the robustness and significance of the observed clustering patterns. This study underscores the importance of integrating spatial analysis techniques into environmental management practices, providing policymakers and stakeholders with valuable insights for sustainable development and pollution control in the Skudai River catchment are.

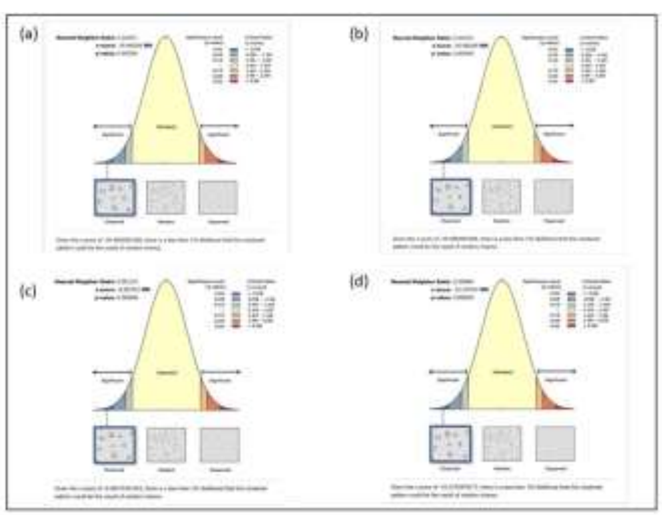

Figure 4: Average nearest neighbor result for each point source pollution; (a) Restaurant, (b) launderette mart, (c) car wash and (d) workshop

5.0 Conclusions

In conclusion, this study sheds light on the spatial distribution patterns of point source pollution in the upstream Skudai River catchment, focusing on restaurants, laundromat marts, car washes, and workshops. Rapid urbanization and industrialization in the region have led to increased environmental challenges, including changes in hydrology, geomorphology, and water quality degradation. The application of GIS technology has been instrumental in unraveling the complexities of point source pollution, providing valuable insights into its spatial dynamics. The analysis revealed distinct clustering patterns for each pollution source category, emphasizing the non-random distribution within the catchment area. The exceptionally low p-values and z-scores further emphasize the statistical significance of these clustering patterns.

Moreover, the study explored the relationship between point source pollution and land use types, revealing concentration hotspots in commercial and residential areas. The transportation sector emerged as a significant contributor to pollution, highlighting the need for targeted environmental management strategies. The proximity of pollution sources to water bodies and the analysis of neighbor patterns provided additional dimensions to the spatial understanding of pollution dynamics. The findings hold critical implications for water resource management, environmental conservation, and urban planning in the Skudai River catchment. The study provides a foundation for informed decision-making, enabling policymakers to devise effective pollution control measures and sustainable land use planning to mitigate the adverse impacts of point source pollution in this critical watershed. Ultimately, this research contributes to the broader discourse on environmental sustainability and the importance of integrating GIS-based spatial analyses for comprehensive and effective environmental management.

The findings have significant practical implications for urban planning, environmental management, and sustainable development. The identified concentration of point source pollution along the riverbanks and within commercial districts highlights the immediate need for the establishment of buffer zones ranging from 500 m to 1 km along the Skudai River and its tributaries, particularly in upstream regions. Municipal authorities must consider stricter regulations and environmental licensing for businesses such as restaurants, car washes, and workshops, especially in commercial and transport zones. Additionally, local authorities may integrate spatial pollution data into zoning regulations and stormwater management plans, in conjunction with the National Water Resources Policy (2012) and Malaysia’s National Urbanization Policy. These initiatives would strengthen Malaysia's commitment to the Sustainable Development Goals, including SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities). Future research should investigate pollution modeling across various urban expansion scenarios and assess the efficacy of policy interventions utilizing GIS-based monitoring systems.

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Conflicts of Interest: The authors declare that there are no conflicts of interest..

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