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Mapping and web-based GIS prediction of pig waste discharge in the Taal Lake

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ABSTRACT

Freshwater ecosystems around the world are under growing pressure from agricultural activities, particularly intensive livestock farming that releases untreated waste into rivers and lakes. In the Philippines, Taal Lake, an ecologically and economically important freshwater resource, has shown signs of declining water quality due to the increasing number of pig farms located along its tributaries. This study developed a web-based Geographic Information System (GIS) to better understand, map, and predict how pig waste is transported from farm locations through the watershed and into Taal Lake. Modelling techniques, including Digital Elevation Model processing, flow direction and accumulation analysis, watershed delineation, and source to stream routing, were used to simulate waste movement along natural drainage pathways. Estimated waste volumes were calculated using pig population data and established waste generation rates, allowing potential pollutant loads to be assessed. The results identified Agoncillo, Tanauan, and Talisay as the most critical areas, with Agoncillo alone accounting for approximately 38.1% of the recorded pig farms. Routing analysis showed that waste from these areas tends to converge along specific tributaries, increasing downstream pollution risks, especially during rainfall events. An interactive web-based map was created using GeoJSON and the Leaflet API to visualize pig farm locations, predicted discharge volumes, flow paths, watershed boundaries, and downstream impact zones. Overall, the study shows that combining GIS analysis with an interactive web platform can support clearer understanding of pollution pathways and provide a practical decision support tool for environmental monitoring and sustainable watershed management around Taal Lake.

Keywords: DEM-based analysis, environmental decision support, sustainable environment

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1. Introduction

Livestock farming plays an important role in feeding populations and supporting rural economies around the world. As livestock and piggery operations continue to expand to meet growing food demands, concerns about how animal discharge is managed have also increased. In many countries, poorly treated livestock discharge finds its way into nearby rivers, streams, and lakes, leading to nutrient pollution, water quality deterioration, and ecological stress in freshwater systems. These problems are not limited to a single region; they have been observed across diverse watershed environments globally, especially in areas where intensive farming is closely linked to natural drainage networks.

In the Philippines, these global environmental challenges are reflected in the condition of Taal Lake and its surrounding tributaries. Taal Lake is a freshwater lake inside a complicated volcanic caldera on Luzon Island, Philippines, 60 km southeast of Manila. With two cities and nine municipalities around it, its total area is 234.2 km^2 [1]. Under the National Integrated Protected Areas System (NIPAS) Act, the lake is part of the Taal Volcano Protected Area. It receives water from 37 tributaries and empties into Balayan Bay via the Pansipit River [2]. The effluents that flow into Taal Lake's tributaries have a significant impact on the water quality, which is home to a variety of aquatic species Taal Lake faces serious pollution problems despite its ecological importance and its involvement in local industry [2].

Understanding and maintaining the lake's water quality is essential because pollution from upland municipalities is carried downstream through its tributaries. Recent environmental reports indicate that illegal manure dumping from small and large scale pig farms has significantly degraded the lake's water systems, especially during the rainy season when runoff intensifies transport of contaminants [2]. According to recent studies, many pig farms operate without the required environmental compliance, which exacerbates pollution problems, particularly in the rainy season [3].

The main cause of the contamination is the uncontrolled animal waste discharge from surrounding pig farms [4]. Unregistered piggeries are a major environmental threat to Taal Lake because they cause fish kills and poor water quality. The primary issue is improper garbage disposal, which puts the lake's biodiversity and ecological health in danger in addition to inefficient aquaculture methods [5]. These piggeries are a major source of income for many barangays, but improper waste disposal contaminates water supplies, endangering aquatic life as well as public health [6]. Insufficient government oversight and resources for appropriate waste management aggravate the problem. As a result, barangays are suffering from diseases spread by water, damage to the ecosystem, and adverse effects on the agricultural and fishing industries' bottom lines.

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The area is so vast and complex that traditional methods of managing and monitoring discharge in the lake have proven inadequate. It is difficult to track the flow of discharge in the lake due to its 37 tributaries, especially during the rainy season when runoff increases. Furthermore, by unlawfully disposing of waste, unregistered pig farms worsen the issue and make it more difficult to identify the origins of contamination.

To overcome these challenges, the study aims to develop a web application that predicts the flow and amount of discharge to the Taal Lake by mapping the elevations, tributaries, and locations of piggeries and visualizing it through GIS. Through the integration of GIS and web technologies, stakeholders can predict and visually represent the volume and flow of discharge released into the lake.

2. Materials and methods

2.1. Design

The first step of the research is the comprehensive collecting of data as shown in Figure 1, with a focus on acquiring as much as possible about the pig farms and tributaries of Taal Lake. Physical information on waterways, tributary features and piggeries' locations was included. For mapping and predicting purposes, accurate data collection was essential.

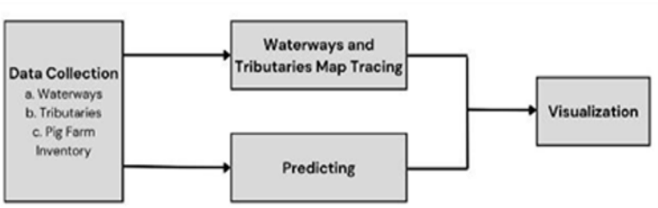

Figure 1. Overview of the study workflow, from data collection and GIS processing to hydrologic analysis, prediction, and web-based visualization.

Next, rivers are mapped using GIS tools, which were used to trace water flow pathways and identify possible discharge routes from pig farms. The analysis of flow direction and accumulation enabled by GIS helped identify locations that were most likely to be impacted by discharge. D-Infinity and D-8 algorithms, for example, were used to model the movement of contaminants throughout the landscape.

After mapping, forecasting models were created using variables like farm size, rainfall, and landscape to predict potential discharge flow situations. The depiction of the research findings using web-based tools allowed stakeholders to interact with interactive maps and investigate high-risk areas. To support researchers, decisionmakers, and the general public in making informed choices, this web interface guarantees accessibility by providing simple navigation and clear display.

Figure 1 depicts the model's process. Several procedures or stages are involved in the system's creation or design, such as dataset preparations, data segmentation, model testing and evaluation, and, finally, model interpretation.

2.2. Conceptual framework

The conceptual framework of the research was shown in Figure 2.

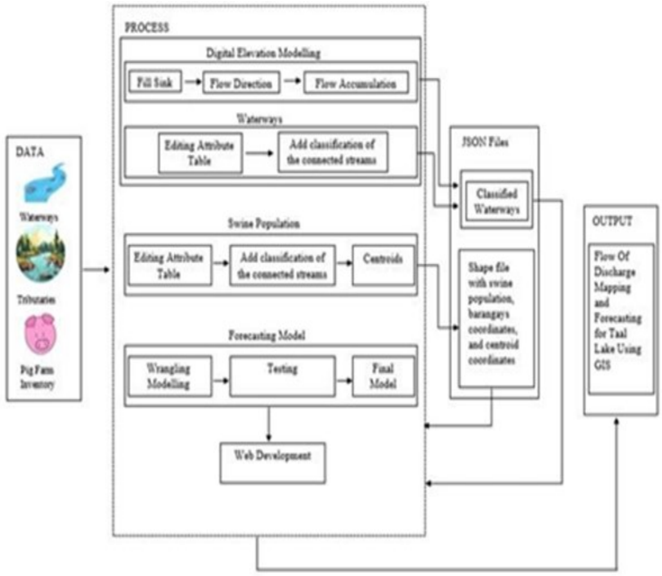

Figure 2. Conceptual framework illustrating how piggery data, hydrologic modelling, and GIS visualization are integrated in the study.

2.2.1. Data collection methodology

To provide the foundation for analysis and conclusions, the research focused on gathering extensive data from barangays, including tributaries, rivers, and pig farms. Local communities were involved through surveys, interviews, and direct observation guarantees accurate and reliable data.

Several scheduled and structured activities were implemented. The researcher first visited the mayors of the surrounding municipalities and cities in Taal Lake to establish contacts, obtain support, and secure permission to conduct research operations within their borders. Getting official permits from these mayors made the research more legitimate and made it easier to access other locations and resources. After that, the researcher worked with barangay officials to organize and arrange visits to particular sites including tributaries, waterways, and piggeries, making sure that local laws and safety requirements were followed. This was done by utilizing their local knowledge.

Firsthand data were collected from the people in each barangay. They visited the waterways and tributaries to observe if there were any pig farms nearby. They also conducted interviews with barangay officials to gather information on existing pig farms and their population data.

While field visits to backyard and commercial piggeries assessed the effects of pig farming on nearby water bodies and the environment, hydrological systems and environmental conditions were assessed at key sites, including tributaries and waterways.

In addition, the researcher mapped the terrain and waterways that feed Taal Lake using GIS technology to collect and evaluate spatial data. With the use of GIS technology and a combination of qualitative and quantitative data collection techniques, the research was made complete, dependable, and contextually informed thanks to this methodical approach. Additionally, the study region was accurately and thoroughly represented.

2.2.2. Processing and analyzing data

The collected data from each municipality were processed and analyzed using QGIS. Correcting pre-existing depressions in the DEM with the Wang and Liu tool was a crucial step in this procedure. This adjustment guaranteed the correctness of ensuing assessments of flow accumulation. The study accurately measured the water flow in the studied area by focusing on this data.

These initiatives made it possible to map out the locations of barangays, including information on pig populations, and to draw boundaries between municipalities and barangays. This made it easier to thoroughly analyze the discharge sources and how they affected the streams that led to Taal Lake.

After the data analysis was finished, the files were converted to GeoJSON format. This translation allowed the data to be integrated with web technologies, and the website could use mapping libraries like Leaflet. GeoJSON was selected as the best option due to its flexibility and adherence to web standards.

2.2.3 Routing of Pig Waste Discharge

In modeling the hydrologic routing of pig waste, each piggery coordinate was first aligned with the nearest flow path within the drainage network. Using the combined D8 and D-Infinity (D∞) flow-direction rasters, the model then traced the complete discharge pathway, beginning at the piggery site and moving downslope following natural terrain gradients, passing through local drainage channels, progressing into the tributaries, and ultimately converging toward Taal Lake. This process generated essential routing outputs, including the delineation of downstream flow paths, the calculation of cumulative contributing drainage areas, and the identification of multiple-path bifurcations characteristic of the D∞ model. Through this comprehensive source-to-stream flow path modeling, the study achieved a more accurate representation of how waste travels through the watershed toward the lake.

2.2.4. Prediction

Analyzing some crucial variables was necessary to predict discharge flow, including the discharge's length, volume, precise location, elevation, tributaries and ultimate destination. Through these parameters, we can predict the amount and flow of discharge. To ensure that tributaries were monitored and managed sustainably, researchers can use hydrological models and geographic information systems (GIS), such as QGIS, to simulate various scenarios, analyze historical data, and make educated predictions.

The Food and Agriculture Organization of the United Nations (FAO) states that pigs typically excrete 60% to 80% of the food they consume daily. Both the United States Department of Agriculture (USDA) and the National Research Council (NRC) agree with this result. By calculating the excretion rate based on the pig's regular feed consumption, which is typically 2.5% to 3.5% of its body weight per day, developers can estimate the average daily discharge volume for each type of pig. Pig weight is divided into several categories: sows weigh between 250 and 300 kg, boar pigs weigh between 300 and 350 kg, fattener pigs weigh between 80 and 100 kg, piglets weigh between 10 and 25 kg (depending on their age), and native pigs weigh between 40 and 60 kg (depending on breed and age).

$$\frac{Discharge}{Day} = Food\ intake\ x\ 70\% \tag{1}$$

$$\frac{Slow\ discharge}{Day\ (kg)} = 8.25\ \text{kg}\ x\ 70\% \tag{2}$$

$$\frac{Boar\ discharge}{Day\ (kg)} = 9.75\ kg\ x\ 70\% \tag{3}$$

$$\frac{Fattener\ discharge}{Day\ (kg)} = 2.7\ kg\ x\ 70\% \tag{4}$$

$$\frac{Piglet\ discharge}{Day\ (kg)} = 0.525\ kg\ x\ 70\% \tag{5}$$

$$\frac{Native\ discharge}{Day\ (kg)} = 1.5\ kg\ x\ 70\% \tag{6}$$

2.2.5. Interactive map

Figure 3, the interactive map allows users to explore various municipalities and barangays to identify potential discharge sources. All hydrologic outputs were converted into GeoJSON format and integrated into the web platform using the Leaflet API, allowing for the display of interactive map layers, dynamic route tracing, and custom markers that identify both the origins and endpoints of waste flow. Through this interface, users can visually explore the spatial distribution of pig farms, estimated discharge volumes, flow direction, flow accumulation patterns, downstream impact zones, and delineated sub-watershed boundaries. This visualization enhances interpretability and supports more informed environmental assessment and decision-making.

Figure 3. Interactive map interface.

The trajectory or path that released materials or discharges follow within the mapped area is shown as the Discharge Path in Figure 4, comprehension of the movement and dispersal of pollutants or waste materials especially those coming from diverse sources like pig farms or urban areas requires an awareness of this image. Users can identify possible impact zones and locations affected by the flow of toxins by highlighting the discharge channel on the map, which helps with environmental assessment and cleanup operations. Moreover, stakeholders can evaluate the overall hydrological dynamics of the Taal Lake region and visualize the interconnectedness between various geographic features thanks to this depiction.

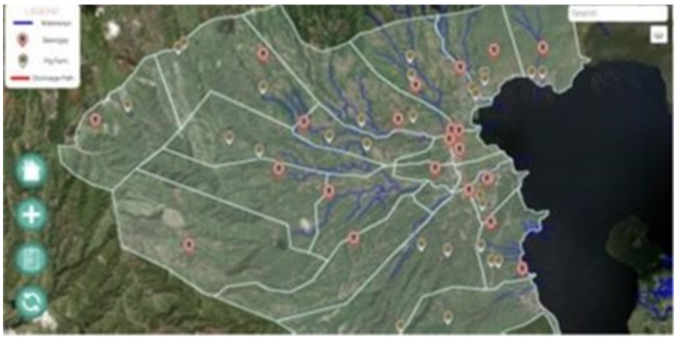

Figure 4. Example of pig waste discharge routing from Laurel, Batangas through connected tributaries toward Taal Lake.

3. Results and discussion

3.1. Demographic data

To obtain demographic data about the area around Taal Lake, information on the population, households, and pig farms were gathered by going to municipal and barangay councils in several towns. By speaking with these authorities, the researcher aimed to verify the accuracy of the demographic and geographical information, ensuring that the data reflected the current state of pig farming operations and waste management practices. Additionally, the researcher sought authorization to access specific locations and gather information, adhering to legal and regulatory requirements. This step validated the reliability of the information and ensured the research complied with local regulations, enhancing its credibility and ethical foundation. They also inspected waterways to evaluate their state. To ensure openness, they communicated with mayors and barangay captains and secured formal authorization to gather data. Furthermore, information from the Taal Volcano Protected Landscape (TVPL) was incorporated to comprehend how human actions interact with the natural dynamics of the protected region. This all- encompassing strategy guaranteed correct data, encouraged teamwork and verified the study's conclusions.

As part of the data-gathering process, the researcher visited every barangay containing tributaries, waterways, and piggeries after obtaining official authority. This required going physically to every barangay to collect first-hand data, evaluate the state of the waterways, and record the existence of piggeries. Through on-site visits, the researcher made sure to comprehend the local context fully and collected precise data that was necessary for the project. Additionally, by allowing for direct communication with community people, this strategy promoted collaboration and strengthened the validity of the study's conclusions.

The distribution of pig farms as a percentage of total municipalities is shown in Figure 5. Agoncillo had the greatest percentage of pig farms 38.1% of any place. Tanauan, the second-highest municipality in terms of pig farming, came in close second with 14.4% of the pig farms. Furthermore, additional municipalities included San Nicolas with 9.9%, Talisay with 12.9%, and both Sta. Teresita and Laurel for 6.9%. Comparatively speaking, the percentages of pig farms in Cuenca were 5.2%, Mataas na Kahoy and Balete were 2.3%, and Alitagtag was 1.1%. Out of all the municipalities shown in the chart, Agoncillo has the highest concentration of pig farms, according to this distribution.

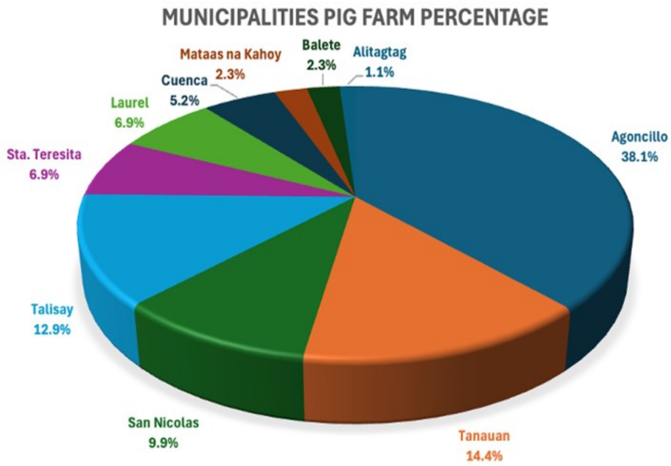

Figure 5. Proportion of pig farms distributed across municipalities surrounding Taal Lake.

Table 1 lists the total number of pig farms in each of the ten municipalities that surround Taal Lake along with piggery data. With 299 piggeries, the Municipality of Agoncillo had the largest number. With nine piggeries, the Municipality of Alitagtag, on the other hand, had the fewest. There were 18 piggeries in the Municipality of Balete, 41 in Cuenca, 54 in Laurel, 18 in Mataas na Kahoy, 78 in San Nicolas, 54 in Santa Teresita, 101 in Talisay, and 113 in Tanauan. The distribution of pig farming operations among various municipalities is shown by the statistics.

Table 1. Total number of piggeries in different municipalities

Code	Name (t)	Total number of piggeries (t)
AGO	Agoncillo	299
ALI	Alitagtag	9
BAL	Balete	18
CUE	Cuenca	41
LAU	Laurel	54
MAT	Mataas na Kahoy	18
SAN	San Nicolas	78
TER	Sta. Teresita	54
TAL	Talisay	101
TAN	Tanuan	113

The researcher worked with the Municipal Planning and Development Office (MPDO) and the City Planning and Development Office (CPDO) in addition to gathering data about piggeries. The required shapefiles, which comprised comprehensive information on the borders, rivers, and waterways inside each area, could only be obtained with this coordination. The researcher was able to precisely map and assess the spatial distribution of pig farms with respect to natural features and administrative boundaries because of the detailed geographical data provided by these shapefiles.

3.2. Map tracing in QGIS

The researcher produced intricate maps that clearly showed canals and regions where flow accumulated using QGIS. These maps developed become essential visual aids for environmental management, allowing for the effective distribution of resources and the accurate identification of crucial regions in need of action. Furthermore, QGIS made it possible to combine demographic and environmental data, which made it easier to conduct a thorough analysis of the environmental effects of pig farming.

Moreover, QGIS made it possible to create interactive maps, which greatly improved stakeholder comprehension of complicated environmental concerns and involvement. This enhanced collaboration between the several parties engaged in putting ecologically friendly management techniques into effect.

The Clipped Digital Elevation Model (DEM) layer and the Municipal Vector Layer are the two levels that are shown in Figure 6. These QGIS-created layers offer local traits or information on a map. For the purpose of displaying elevation data, terrain contours, and water flow directions, the Clipped DEM is essential. In the meantime, the Municipal Vector Layer shows the geographic relationships between municipalities and natural features by outlining administrative boundaries. When combined, these layers provide a strong framework for illustrating how rivers and streams come together to produce the lake.

a)

b)

Figure 6. (a) Clipped DEM later (b) A municipal vector layer

The Filled DEM layer, which has been adjusted to correct all terrain sinks or depressions, is shown in Figure 7, along with a specific subset of lake areas. These actions were carefully carried out to guarantee accuracy and consistency in the waterway analysis. The surface is smoothed and potential mistakes and discrepancies from uneven terrain are minimized by filling the DEM layer. Furthermore, by eliminating superfluous detail and improving the clarity of the resulting stream order, hiding the lake areas streamlines the analysis.

Figure 7. Filled Digital Elevation Model Layer.

The Taal Lake waterways under analysis are shown in Figure 8. These layers can be layered and examined in QGIS to provide important insights into the hydrological features of a municipality, including flow pathways and watershed boundaries. The data, which were shown using Google Earth Pro, were crucial for determining how accurate hydrology analysis tools were and for fine-tuning the resultant flow routes as needed. To guarantee the precision and dependability of the depicted hydrological features, a thorough examination of the vast water flow network was conducted. We visited a few of the designated tributaries to confirm their accuracy and status.

Figure 8. Tributaries waterways in municipal boundaries layer.

3.3. Predict the discharge flow within tributaries, including the volume, exact locations of the tributaries, and the destinations of the discharge

To predict discharge flow in waterways, the researchers used hydrological models and GIS tools, specifically QGIS, to assess variables such as discharge flow, including the discharge's length, volume, precise location, elevation, tributaries, and ultimate destination. They were able to generate well-informed projections that are essential for managing water resources, preventing floods, and protecting the environment by modeling different scenarios and examining historical data. The development of an approachable platform to gather discharge data from pig farms along waterways that lead to Taal Lake was a significant result of this research. As depicted in Figure 9, this platform provides comprehensive information on pig farms, tributaries, and their closeness to the lake by integrating spatial data analysis. While the backend system determines the pig effluents, the interactive map on the platform shows the locations of pig farms and streams that contribute to discharge volumes. This tool is handy since it helps with the evaluation of the cleanliness of waterways by enabling users to locate possible sources of contamination. Stakeholders can more effectively manage environmental health and create pollution mitigation plans by identifying pig farms and evaluating the discharge impact of these facilities.

Figure 9. Estimated pig waste discharge volumes mapped along tributary networks.

In general, the platform improves knowledge of the ecological effects and spatial distribution of pig farm discharges, which helps with better management and preservation of the Taal Lake ecosystem.

Researchers may map and examine geographic features like rivers and tributaries using QGIS and shapefiles. They are capable of carrying out spatial assessments such as watershed delineation, monitoring upstream flow patterns, and buffering around bodies of water. This aids in identifying the locations and routes of tributaries, highlighting the connectivity of water bodies and the influence of upstream activities on downstream ecology and water quality. Water flow as shown in Figure 10 is represented graphically from sources to discharge locations, such as lakes or oceans, which helps with targeted pollution control and well-informed land use planning. It gives interested parties a thorough understanding of how water moves across ecosystems, natural areas, and populated areas.

Figure 10. Destination of discharge toward Taal Lake.

4. Conclusions

Livestock pollution from piggery operations remains a serious concern in lake-bound waterways, where discharge can easily move through connected tributaries. This study addressed this concern by developing a web-based GIS framework that combines hydrologic routing with interactive visualization to clarify how pig discharge travels toward Taal Lake. Using a source-to-stream, waterways scale perspective, the approach goes beyond static maps and helps reveal likely pollution pathways and impact areas. The study's main contribution is demonstrating that hydrologic GIS analysis, when presented through an accessible web platform, can support practical environmental monitoring, planning, and decision-making. The framework offers useful guidance for local governments and environmental managers and can be adapted to other freshwater systems facing similar livestock related pressures in rapidly changing agricultural landscapes.

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