Site Suitability for Aquaculture Development on the Caroni River Basin, Trinidad West Indies Using GIS

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ABSTRACT

Several successful aquaculture ventures have been initiated in the Caroni River Basin, Trinidad, which is a major catchment area supplying water to fill domestic and agricultural irrigation needs. Aquaculture development in this region will serve to provide alternative livelihood opportunities, increase protein availability and as a model for other regions of Trinidad. Geographic Information Systems (GISs) can serve to promote aquaculture by providing an analytical and predictive means for development, management and testing of development consequences. This study involved the production of a GIS to determine potential aquaculture sites in the Caroni River Basin. The analytical work consisted of the determination of evaluation criteria for freshwater fish farming using inland ponds based on: water quality, quantity and availability; proneness to flooding; soil type; topography; land use/land cover; and infrastructure, and the development of a GIS application for aquaculture siting. Results included: established selection criteria for aquaculture site suitability; an adequate GIS database consisting of the physical, environmental and socio-economic data; a site suitability assessment using GIS analysis and modeling; and optimum aquaculture development sites in the Caroni River Basin. Most of the aquaculture site locations were predicted in the southern region of the Basin. The total area of these sites measured 11,400 hectares (ha), ranging from 0.06 to 57,783 ha. The study demonstrated the associated advantages and the analytical abilities of GIS as an aquaculture-planning tool for the Caroni River Basin, where the scarce remaining natural resources are under severe environmental pressures.

KEY WORDS: Aquaculture, Geographic Information System (GIS), Site Suitability

Localización de Sitios para la Acuacultura en la Cuenca del Río de Caroni, Trinidad Usando GIS

Se han iniciado exitosamente algunos trabajos de acuacultura en la Cuenca del Río Caroni, Trinidad, que es un área de estancación principal abastecedora de agua para satisfacer las necesidades de irrigación agrícola y doméstica. El desarrollo de la acuacultura en esta región servirá para proporcionar oportunidades alternativas de subsistencia, aumentar la disponibilidad de proteína y también como un modelo para otras regiones de Trinidad.

Los Sistemas Geográficos de Información (SGI) pueden servir para promover la acuacultura proporcionando medios proféticos y analíticos para el desarrollo, administración y el examen de las consecuencias del desarrollo. Este estudio incluyó la producción de un SGI para determinar los posibles lugares de desarrollo de Acuacultura en la Cuenca del Río Caroni. El trabajo analítico consistió en la determinación de los criterios de evaluación para cultivo de peces de agua fresca utilizando lagunas de la isla basada en: calidad, cantidad y disponibilidad del agua, precipitación; propensión a la inundación; tipo de suelo; elevación; uso de la tierra; infraestructura y límites administrativos, y el desarrollo de una aplicación de SGI para un sitio de acuacultura. Los resultados incluyeron criterios del objetivo establecido para el desarrollo de la acuacultura; una adecuada base de datos del SGI que consiste en datos socioeconómicos, medioambientales y físicos; una valoración de la conveniencia del lugar utilizando el análisis de SGI y modelaje; y lugares óptimos para el desarrollo de la acuacultura en la Cuenca del Río Caroní. La mayoría de las ubicaciones de los lugares de desarrollo de acuacultura estuvieron situados en la región norte de la cuenca. El área total de esos lugares midió 23,803 hectárea con tamaños de los lugares fluctuando entre 0.5 a 6,970 hectáreas. El estudio demostró las ventajas asociadas, y las habilidades analíticas del SIG como un instrumento de planificación de la acuacultura en la Cuenca del Río Caroni, donde los escasos recursos naturales restantes están bajo severas presiones medioambientales.

PALABRAS CLAVES: Acuacultura, Sistema Geográfico de Información (SGI), sustentabilidad del lugar

INTRODUCTION

The prevailing climatic conditions, physical land and water resources in Trinidad are favourable for freshwater aquaculture. However, there is lack of a strong aquaculture industry due to: a relatively rich marine fishery, high cost for land and water and, aquaculture not being a tradition in Trinidad and Tobago, West Indies. As a result, farmers and investors are hesitant to enter into aquaculture projects. In an effort to guide future aquaculture ventures to success, the Trinidad government has formulated a National Aquaculture Policy (2002 - 2005). Proper aquaculture planning also requires knowledge of prospective locations, which show the most promising development potential. This increases the chances of a positive return on investment of resources.

Therefore, site suitability is a key factor in aquaculture planning and development.

Environmental conditions present both constraints and opportunities for aquaculture operations. These considerations are vital in anticipating and avoiding adverse site selection. Site suitability requires analysis of the critical factors for its success and sustainability. Aquaculture planning must be based on a comprehensive analysis of natural resource conditions in an analytical framework that can incorporate the spatial dimensions of environmental parameters that affect its sustainability. This is necessary in order to produce a framework to guide decision-makers in allocating scarce resources among competing interests.

Geographic Information Systems (GISs) can elucidate interactions involved in the environment by incorporating spatial and process analysis capabilities. GIS capabilities for organizing adequate databases of relevant spatial data and integrating them into useful models are necessary for a comprehensive site suitability assessment. Numerous aquaculture site suitability studies covering large and small geographic areas have been completed using GIS technology. These include: continental level assessment for Africa (Kapestky 1994), refined to include biogenetics modeling and fish yield estimates (Aguillar-Manjarrez and Nath 1998); regional level assessments for Latin America (Kapestry and Nath 1997) and the Caribbean Islands (Kapestry and Chakalall 1998); country level assessment for Pakistan (Ali et al. 1991); county and island level studies (Kapetsky et al. 1988, Ross et al. 1993, and Perez et al. 2003); gulf assessment in Costa Rica (Kapetsky et al. 1987); and bay assessment in Bangladesh (Salam et al. 2003).

Kapestry and Chakalall (1998) indicates 100 percent relative area suitability for small-scale inland fisn farming in Trinidad and Tobago. Kenny (1981) and Ramnarine et al. (1994) have identified several suitable sites for freshwater fish farming in Trinidad and Tobago. However, these studies are country level assessments with limited systematic spatial data analysis. The Caroni River Basin was chosen as the study area for several reasons. It offers a number of key essentials for aquaculture in an environment with competing land and water uses, includes the most abundant fresh water resources in Trinidad; two major aquaculture ventures have existed here for a long time, and there is sufficient availability of relevant data for the area.

This paper presents the results of a GIS application to assess the land suitability for semi-intensive freshwater aquaculture in the Caroni River Basin, Trinidad. The study focuses on semi-intensive fish farming in ponds because it is the most popular and technically feasible aquaculture practice in Trinidad. The primary objective was to develop a GIS model designed to identify potential aquaculture sites for semi-intensive fish farming in the Caroni River Basin. This study is useful for understanding aquaculture potential and promoting the use of quantitative spatial data in a model case for planning aquaculture development in Trinidad.

MATERIALS AND METHODS

Study Area

Trinidad and Tobago is a twin island Republic situated between 10° and 12° North Latitude and 60° and 62° West Longitude. Trinidad is the most southerly island of the Caribbean islands, and the study area is located in the northwestern section of Trinidad. It includes the capital city, Port of Spain and occupies an approximate surface area of 883 square kilometers (km^2) (Figure 1). The Basin contains the Caroni River, the largest river in Trinidad, which drains the northern and central ranges in a westerly direction into the Gulf of Paria. Thirteen percent of the river basin is designated as forest reserve. It encompasses the largest mangrove area in Trinidad, which is of economic importance to the oyster, fish and ecotourism sectors. The area also supports light industrial estates, livestock farms and intensive agriculture, from which effluents, pesticides, herbicides, fungicides and fertilizers are often discharged directly into the Caroni River and some of its tributaries. Other pollution sources are quarrying activities, secondarily treated sewage, and domestic waste disposal.

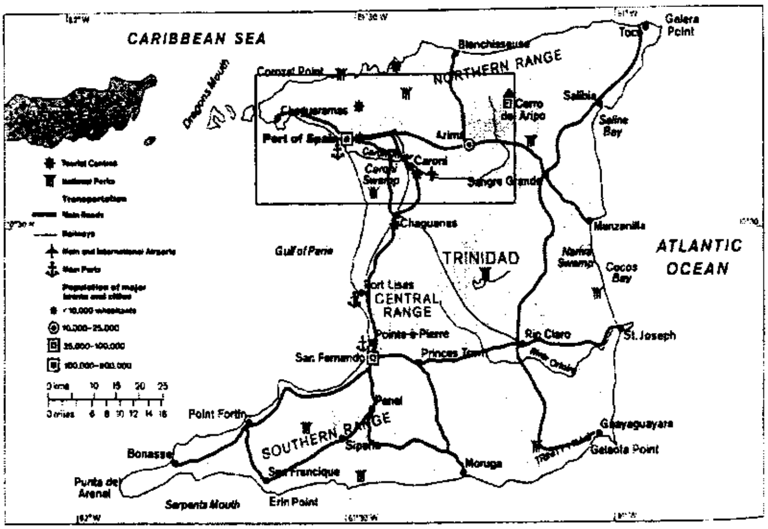

Figure 1. The island of Trinidad and the Caroni River Basin

Analytical Framework

The analytical framework for this study is limited to the assessment of land-based potential for semi-intensive freshwater aquaculture. The main procedures were:

i) Identification of essential criteria and corresponding thresholds;
ii) GIS database construction for integration of criteria data;
iii) GIS manipulation and modeling for site suitability assessment;
iv) Evaluation and interpretation of the results; and
v) Analysis refinement as necessary.

Criteria for Aquaculture Assessment

Typical specifications for small (approximately two hectares) semi-intensive freshwater fish farming in ponds are: earthen ponds with aeration for culturing Red Hybrid Tilapia, Cascadura (*Hoplosternum Littorale*) and Prawns (*Macrobrachium Rosenbergii*), fed on an artificial ration for annual production estimates of 20,000 kg/ha, 12,000kg/ha and 8,000 kg/ha, respectively. The most important factors and constraints influencing the site suitability for this system of aquaculture provided the basis of the assessment. Practical selection criteria and ranges of data (or thresholds) were established for site evaluation. Each criterion was scored on a suitability scale of one to four. The scoring levels correspond to the level of suitability: Optimal (1), Suitable (2), Marginal (3) and Unsuitable (4). This classification scheme was applied for manageability of analysis and to ensure comprehensible and comparable results. In addition, the scheme was used to standardize or normalize the data layers in the GIS. Threshold values pertaining to the desired levels of suitability for each criterion were defined through:

i) Interpretation of available data;
ii) Adaptations of criteria used in previous studies, particularly Kapetsky (1994) and Aguillar-Manjarrez, J. and S.S. Nath (1998); and
iii) Guidance from aquaculture experts at the Institute of Marine Affairs (IMA).

The three categories of criteria and their corresponding thresholds established for the assessment are summarized in Table 1. They include constraints, land use/land cover and infrastructure and physical and environmental conditions. Constraints are all the geographical areas within the Caroni River Basin that are unavailable for aquaculture development. Physical and environmental factors describe the influential resources and conditions necessary for successful and sustainable aquaculture development.

GIS Database Construction

The GIS software utilized consisted of Arc View GIS Application software version 3.2, Arc View Spatial Analyst and Arc View 3D Analyst, produced by the Environment System Research Institute (ESRI). The software enabled database creation, digitizing, data manipulation and modeling to reveal potential aquaculture sites.

Table 1. Summary of Criteria and Thresholds for Small-Intensive Fresh Water Fish Farming

Data Layer	Critical Factor	Optimal Criteria	Suitable Criteria	Marginal Criteria	Unsuitable Criteria
			Constraints		
Highway & Road reserve and setback River Reserve	50m H'way. 15m Road 10m River				50m H'way Buffer 15m Road Buffer 10m River Buffer
SENSITIVE AREA	Dams				Dams
BUFFER ZONE	Dykes				Dykes
NON-POINT POLLUTION SOURCES	WDS				WDS
			Land Use and Infrastructure		
LAND USE/LAND COVER	Land Use and Land Cover		Agriculture Mixed Forest		Forest Reserve Industry Institution Quarry Recreation Residential Swamp
			Physical and Environmental Factors		
SLOPE	Slope/ deg.	0-3	3-6	6-9	>9
SOIL	Clay/ %	>30	20-30	20	< 20
SURFACE WATER	Rivers		Unpolluted		Polluted
WATER QUALITY	WQI of Rivers		Good		Poor
FLOODING	Flood Zones	Unlikely	Slight	Rare	High

Baseline data from several sources describing the different criteria were digitized and organized into thematic data layers. Topography, rivers, roads, dams, wetland, forest reserves, towns, and land use/land cover were sourced from the 1978 1:25,000 Topographic Map Sheets [Series: E804 (D. O. S. 316/1] of Trinidad. Dykes were extracted from the 1994 1:150,000 Trinidad Hazard and Response Map. Soil lithology data were extracted from the 1971 1:150,000 Trinidad Soils map. Areas subjected to flooding were extracted from the 1999 Flood Prone Areas Map of Trinidad from the National Emergency Management Agency (NEMA). Water quality data were obtained from the Surface Water Quality Monitoring Study in the Caroni River Basin report (IMA, 2000). All the data were geo-referenced to a common referencing system, characterized by: the Transverse Mercator zone 20 projection; the Universal Transverse Mercator (UTM) coordinate system, the Trinidad Naparima 1955 datum and metric units of measurement in metres (m).

GIS Modeling

The GIS was designed to model the selection criteria, based on available data, and to perform spatial analyses for the identification of potential aquaculture sites. The final thematic data layers describing the selection criteria and constraints were logically integrated into suitability sub-models for constraints, Land Use/Land Cover, Water Availability, Flood Prone Areas and Soil and Topography.

Constraints Sub-Model — Unavailable areas for aquaculture including: protected lands - forest reserves, wetlands and dams; areas with development restrictions – road and highway reserves and set-backs and river reserves; and areas of known or suspected contamination – waster disposal sites, housing and industrial sites. All of the above are considered to be constraints to site suitability assessment. Buffers of 10 m distances were generated along the major tributaries in the study area to represent development restrictions for rivers. The highway and road development restrictions were developed by buffer generations of 30 m and 15 m distances along the highway and first class roads respectively. The data layers representing the constraints were combined into one data layer for exclusion from the assessment.

Land Use/Land Cover Sub-Model — Considerations for land suitability for aquaculture was characterized by agriculture and mixed forest for minimal land use conflicts. Agriculture is an important indicator of aquaculture potential because it implies the presence of minimal infrastructure and a possible source of fish feed or fertilizer from the agricultural by-products for increased yields (Kapetsky and Nath 1997). All other categories including residential, industrial, institutional, quarrying, recreation and wetland were scored as unsuitable because they were regarded as potential sources of pollution. These data were eliminated during the assessment for suitable available land.

Infrastructure data are important to aquaculture site suitability because they address the operational viability with regards to easy access to transportation, market, labour, utility services, and other necessary conveniences. However, this factor is unique because it depends on personalized preferences for different infrastructure requirements for location and available transport options. This factor cannot be easily modeled due to the lack of formula for predicting the success of a new aquaculture venture based on the existing infrastructure in site selection (McIntosh 2002). This posed some difficulty in selecting infrastructure criteria and thresholds. Since the road network is generally appropriate to meet the aquaculture requirements, it was only necessary to exclude the development restriction zones for highways and roads, which were included in the constraints data layer.

Water Availability Sub-Model — An adequate quantity of good quality water is vital to the sustainability of any semi-intensive aquaculture operation. The major sources of surface water are the network of perennial tributaries, the Caroni River, reservoirs and dams existing in the Caroni River Basin. The Caroni river system is the major contributor to the portable water supply of Trinidad (EMA 1998). Surface water quantity varies from the dry (January to

May) to the wet (June to December) seasons. Of the 2,500 million cubic metres (MCM) estimate for surface water availability for Trinidad, only 513 MCM (20 %) is available in the dry season (EMA 1998). Although, the water quality of many of the rivers is degraded by numerous pollutants, a 1997 surface water quality monitoring study of the Caroni River Basin revealed poor water quality in the lower sections of the San Juan, St. Joseph, Tacarigua, Arouca, Arima, Guanapo, El Mamo, Aripo, Caroni, and Cunupia Rivers (IMA 2000). The Relative Water Quality Index (RWQI) developed for the study rated the lower sections of the San Juan, St. Joseph, Tacarigua, and Cunupia Rivers as unacceptable, the upper sections of the Guanpo River as acceptable and the remaining rivers as partially acceptable (IMA 2000). Suitable conditions of water quality and quantity resulted after the exclusion of potential pollution sources and areas highly prone to flooding in the sub-models of land use and areas prone to flooding, respectively.

Flood Prone Areas Sub-Model — The study area is located in a flood plain, rendering this aspect critical. Sites in locations with high susceptibility to flooding can lead to impassable roads, obstructing access to markets, overflow of ponds, coliform bacterial contamination of fish, and economic loss to farmers. The flood prone areas map received from NEMA was geo referenced using PCI's EASI/PACE version 7.0 GCP Works Module, at a root mean square error of 1.0 m. This was followed by heads-up digitizing to incorporate this data into the GIS database.

Soil and Topography Sub-Model — Soil texture and slope are important in the identification of suitable sites for construction of ponds (Kapetsky 1994). These criteria are required for engineering capability evaluation for pond construction at minimum costs (Aguillar-Manjarrez and S.S. Nath 1998). Soil must contain sufficient clay to be able to hold water, with limited compaction being necessary. The clay content of the different soil types in the Caroni River Basin was interpreted using the USDA Soil Texture Triangle. The resulting criteria data were reclassified into their corresponding suitability scores.

Slope criteria sought to make use of gravity for efficient drainage to and from the ponds (Aguillar-Manjarrez and Nath 1998), however, slopes must not be too steep for economic earthworks. Slope criteria data were initially derived from slope generation of a Digital Elevation Model using the TIN (Triangular Irregular Network) model from contour data. These resulted in data incompatibility issues and were replaced by slope data derived from the 1971 land capability studies of Trinidad, for development of the sub model. New slope criteria and thresholds for slope data in degrees were computed from the initial slope criteria in percentages before the data was classified into suitability ratings.

All the sub-models were combined in the final analysis to determine their overall spatial correlation and lead to the identification of potential sites, which were ranked according to their suitability. The procedures and GIS operations involved in the classification and evaluation of selected sites are outlined in the cartographic model in Figure 2.

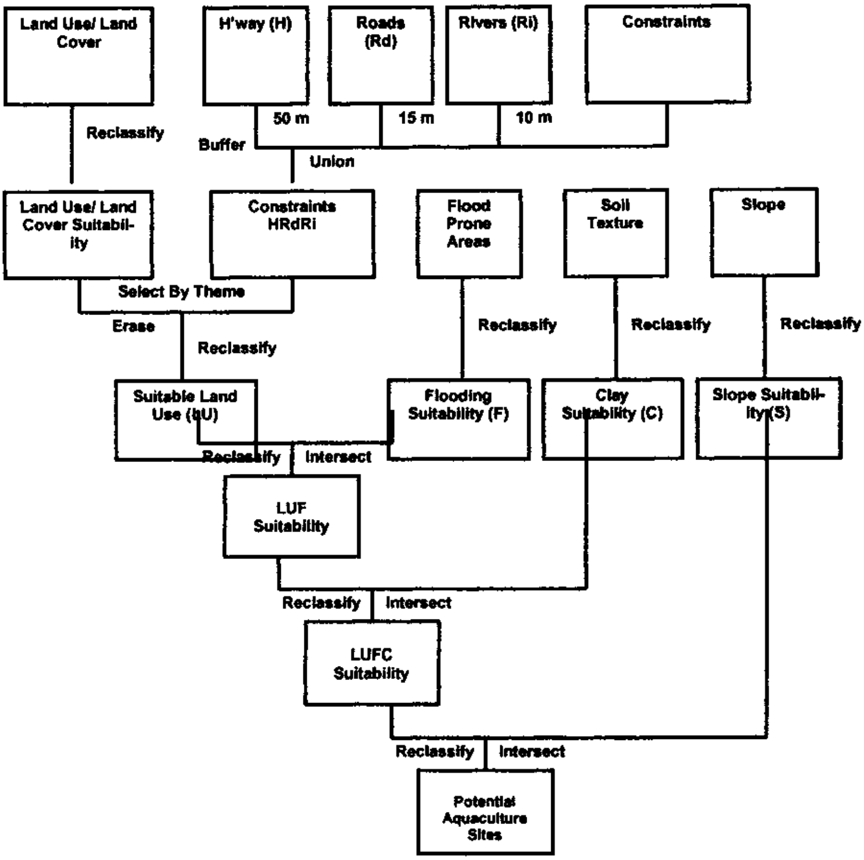

Figure 2. Flow chart of the GIS operations performed in the site suitability assessment for semi-intensive freshwater aquaculture.

RESULTS

The results of each sub model and the final analysis are summarized in Table 2. Spatial distributions of the suitable sites selected are illustrated in Figure 3.

The final results highlight the suitability of the southern region of the Caroni River Basin for freshwater semi-intensive pond systems (Figure 3). Most of the potential sites with optimal and suitable ratings are situated in close proximity to the rivers where freshwater is most abundant. No marginal sites were indicated because of suitable soil texture, topography, and good water quality and quantity of the existing rivers: Cumuto, Talparo, Tumpuna Rivers ,and the southern sections of the Cunupia River. Suitable sites were also indicated in the northern region of the Caroni River Basin, between the St. Joseph and the Valencia Rivers (Figure 3). Optimal sites were identified between the Oropuna and the Valencia rivers. A very large suitable site measuring 282 ha was identified in the Heights of Guanapo and is divided by the Tumbason River into two areas of 59 ha and 222ha. All the criteria are suitable in this location except for topography, which is marginal due to slopes of 5 - 10 degrees. The largest optimal site measuring 297 ha was identified along the Cumuto River. The second largest optimal site measures 90h a in Las Lomas followed by a site of 69 ha situated between the Acuna and Caura rivers in the Maracas Valley. These sites satisfy all the optimal criteria as indicated in the sub-models. Generally, these areas have adequate infrastructure and an abundant supply of good water quality.

Table 2. Summary of results expressed as percentages of the total surface area of the Caroni River Basin.

Sub-Model	Optimal (%)	Suitable (%)	Marginal (%)	Unsuitable (%)
Constraints				5.48
Land Use/Land Cover		68.80		31.20
Soil	34.92	28.17	3.54	32.11
Slope	28.86	19.86	12.49	37.52
Soil and Topography	15.26	15.42	3.91	65.41
Flood Prone Areas	56.72	13.29	9.40	20.59
Predicted Sites	1.79	11.16	0.09	86.95
Predicted Sites >=20,000 sq m	1.74	10.75	0.08	-

The combination of soil and slope characteristics is the most limiting of all the sub-models for optimal sites, with the lowest value of 15.26 % of the Basin's surface area being classified as optimal (Table 2). Although, there were high percentages of optimal and suitable soils, 35 % and 28 %, respectively, when combined with the slope data, only 15 % optimal and 15 % suitable sites resulted (Table 2). This result seems to be due to the spatial distributions of the soil and slope suitability scores, which indicated little spatial correlation between optimal and suitable soils and slopes. Overall, the marginal sites were indicated in either areas of marginal soils and slopes or in areas of suitable soils but unsuitable slopes. Unsuitable sites are mainly located in the lower regions that are prone to frequent flooding.

The results are supported by the fact that five out of the six existing farms were located at suitable sites predicted by the GIS. The other farm is located in high flood prone areas, which are rated as unsuitable sites for aquaculture in this model.

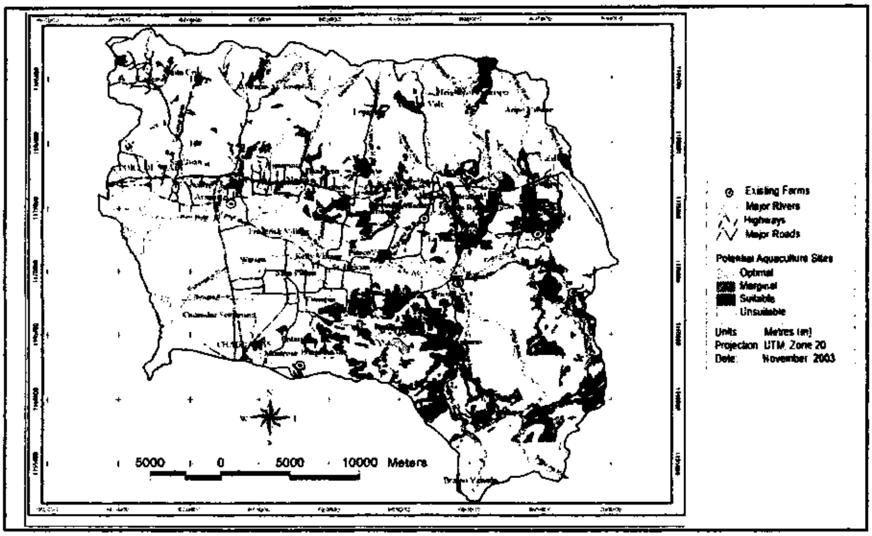

Figure 3. Spatial distribution of optimal, suitable, marginal, and unsuitable aquaculture sites predicted by GIS

DISCUSSION AND CONCLUSION

The study demonstrates that integration and spatial analysis of relevant environmental and physical parameters from diverse sources can be evaluated for interpretation of site suitability in aquaculture planning. However, the results are only indicative of aquaculture opportunities and further field investigation and verification is necessary prior to embarking on development programmes. In addition, the results have been influenced by several factors that impose limitations on the confidence of the GIS model outputs. These factors include: data inaccuracy, spatial and temporal data availability, surrogate and derived data, criteria thresholds and the analytical approach (Nath et al. 2000, Aguillar-Manjarrez and Nath 1998, and Kapetsky 1994).

Partial verification was achieved by comparing the GIS outcome with the locations of aquaculture farms already existing in the Caroni River Basin.

None of the optimal sites matched the existing farm locations, which means that these opportunities are not yet under culture and may be developed for aquaculture. In addition, the 114 km^2 of optimal and suitable sites predicted by the GIS model, gives an indication of the potential of aquaculture as an alternative source of income in the Caroni River Basin. This alternative is versatile and sustainable because it can be integrated with traditional agriculture practices (without the use of pesticides) and operated on a seasonal basis.

The GIS model presented here can be modified to: include more evaluation parameters for a more comprehensive assessment of the aquaculture development potential, apply and examine weights to the selection criteria, and integrated with fish yield productivity and biogenetics models.

The methodology presented was successfully applied to identify optimal, suitable, marginal, and unsuitable sites for small semi-intensive freshwater fish farming for an inland aquaculture pond system in the Caroni River Basin. This GIS application demonstrates the effectiveness of GISs in predicting site suitability for planning watershed aquaculture development, particularly in areas of competing land uses that require sustainable and environmentally sensitive development solutions.

The application is useful to national planners and decision makers in deciding the most appropriate aquaculture sites in areas of keen competition for many diverse land use activities. Bearing in mind that food security is of paramount importance and that local marine fishing areas are being adversely affected by land-based industrial activity and offshore oil and gas exploitation, it is important that the most suitable sites be identified if the option of freshwater aquaculture is to be considered in the future.

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