GIS-based Modeling in Greater Mymensingh for Sustainable Aquaculture Development and Management

Final Report

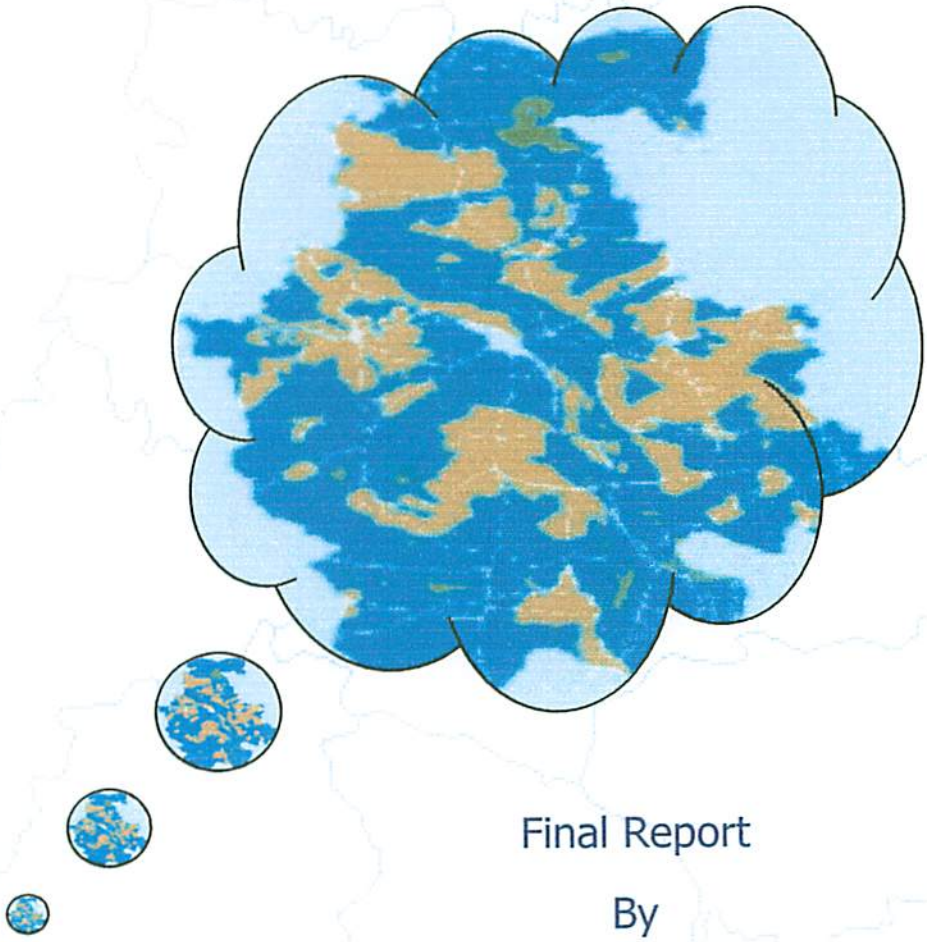
By

Dr. M. A. Salam
Assistant Professor
Department of Aquaculture
Bangladesh Agricultural University
Mymensingh-2202, Bangladesh
E-mail: salam@royalten.net
salam_121268@yahoo.com

December 2004

WorldFish
CENTER

GIS-based Modeling in Greater Mymensingh for Sustainable Aquaculture Development and Management



Final Report

By

Dr. M. A. Salam
Assistant Professor
Department of Aquaculture
Bangladesh Agricultural University
Mymensingh-2202, Bangladesh
E-mail: salam@royalten.net
salam_121268@yahoo.com

December 2004

WorldFish
CENTER

Contents

GIS-based Modeling in Greater Mymensingh for Sustainable Aquaculture Development and Management

Executive Summary

The purpose of the study was to identify the potential site for sustainable aquaculture development in Mymensingh district using GIS as a tool. Six main categories of criteria were considered to locate areas suitable for development of sustainable aquaculture potential followed by the approach of Kapetsky (1994), they were water sources, soil quality, infrastructure, market potential, agricultural input and extension support facilities. Data were located, colleted and compiled from different government and non-government organizations of the district along with the field survey where necessary. Then the relevant data were transferred in to computer for storing and analysis by keyboard, digitizer, scanners, CD-ROMs, computer-compatible taps, floppy discs, pen drives, or via networking from external sources. The collected maps were scanned as BMP format, which then imported into IDRISI to incorporate into the GIS databases using import facility and attribute data were added using keyboard. Raw data were measured on different scales which needed a standard classification method. Each of the layers with associated attribute data was digitally encoded in a GIS databases to create thematic layers. Sub-models were created using the similar type of data. The GIS database was prepared by giving each factor and sub-models a physical score from 1 to 4. Then they were weighted prior to use in MCE module to obtain potential sites for fish culture in the area. Finally, constrains were incorporated along with the sub-models to keep away the build up and naturally sensitive areas from consideration.

The GIS model identified 24% (99,415 hectares) area, which is under very suitable category, and 74% (302,754 hectares) land parcel is under moderately suitable category for potential sites intended for sustainable aquaculture development in the area. The land parcel under marginally suitable category is only 1% (5,359 hectares) and currently unsuitable category is completely absent for potential sites for aquaculture development in the study area. Moreover, most of the marginally suitable area is situated in Dhabaura Upazilla due to lack of essential components needed for successful fish culture operation. The very suitable area is scatteredly distributed all over the district, although most the area is located near Mymensingh sadar, Trisal, Ishargonj, Muktagacha Fulpur and Gaffargaon Upazilla of the district due to most of the criteria coincide well for fish culture in those areas. The results of this study are indicative of the modeling power of GIS for this application and could be used to refine the models in future, particularly if supported by further detail field data. For further developments, it could be important, that a detailed study is made for the availability of agricultural by-products, especially mustard oil cake, rice bran, wheat bran and animal wastes, which could be used as low cost feed for sustainable aquaculture development in the area or any were else in the country or region.

1. Background

In recent years, like other developing countries, Bangladesh is facing three critical challenges of combating poverty, meeting current and future demands for food and nutrition and ensuring employment opportunities for its rapidly increasing population. About 80% of the population depends on agriculture and related activities (Mazid, 2002). However, land based opportunities are limited, on the other hand, the vast and diverse water resources offer the best opportunities for sustainability in food production and economic development. Among the aquatic biomass, fisheries and aquaculture industries play a significant role in contributing fish protein to a booming population of Bangladesh many of whom suffer from chronic malnutrition (Ravenholt, 1982). It is providing direct employment of fishermen and indirect employment in fishery-related industries; assisting in the socio-economic stability of the rural areas and also assisting to earn foreign exchange through increasing export of fish commodities (Chaua, 1986).

Population growth is creating great pressure on land, water, space and food production. More food protein needs to be produced and a contribution can be made to this by increasing fish production through extension of aquaculture and inland fisheries. The scopes for inland aquaculture is indicated by the projected decline in world capture fisheries over the next few decades (Meaden and Kapetsky, 1991). A realistic and practicable way of supplying more food protein is to increase fish production through extension of aquaculture and freshwater fisheries as the capture fisheries are declining day by day (FAO, 1997). However, the production sites for these activities need to satisfy fairly complex location criteria, it would be better if suitable areas were identified in advance. Therefore, future aquaculture development programs should be planned for all economic levels and all location (Muir, 1995).

Increased production can be achieved by the expansion of areas of land under culture, and the use of more intensive and modern farming technologies that involve higher usage of inputs such as water, feeds, fertilizers and chemicals. Higher inputs normally give rise to increased wastes discharges from farms; and extensions of cultivated areas, whether on land or water, give rise to conflicts with other users of the resources. Socio-cultural and economic impacts of same of the large-scale projects have not always benefited the disadvantaged local populations, although this was one of the major aims of development, especially in developing countries. As a result, aquaculture, which was once considered an environmentally sound practice because of its traditional polyculture and integrated systems of farming based on optimum utilization of farm resources.

Assessment of suitable sites is fundamental for planning for aquaculture expansion. Applying appropriate criteria, both environmental and socio-economic, can do potential sites for various types of aquaculture developments. Earlier, site selection was aimed at ensuring economic profit and increasing production, but at present, environmental factors are used to ensure sustainable development. Appropriate socio-economic factors will ensure the profitability of the industry, while environmental factors will maximize production and prevent adverse impacts on the environment (Jarayabhand, 1997).

For proper planning, management and sustainable development of aquaculture in a particular area, it is necessary to identify the specific problems of that area. Knowing the prevailing conditions of different farming situations through a detailed survey can identify these problems. Once the problems are identified and necessary measures taken to overcome those problems then only then it is possible to obtain sustainable production of aquaculture. To identify the problem of sustainable aquaculture we can use Geographical Information Systems (GIS) as a tool. By using GIS modeling technique, we can select the suitable place for aqua farm establishment. If the farmers make fishponds without considering prior survey they may face many natural disorders. So, farmers should maintain proper system before establishment of an aqua farm. GIS is a set of computer-based systems for managing geographic data and using these data to solve the spatial problems. A GIS is a combination of hardware and specialized software that is used to store, manipulate and analyze data of diverse kinds with a common Geographic base. With such automation, reporting can be in the form of tabular data, graphics and, most importantly maps (Aronoff, 1989; De Mers, 2000 and Clarke, 2001). Application of GIS in aquaculture is only recently becoming to be reported (Kapetsky *et al.* 1987).

The benefits of GIS applications in aquaculture have promoted its quick expansion. Meaden and Kapetsky (1991) and El-Gayar (1997) point out the advantages of using GIS in aquaculture planning:

- The use of GIS allows easy analysis and re-analysis of different scenarios by varying the initial assumptions and criteria. The consequences of this advantage can be clearly seen as a quicker approach to solve the problem,
- allowing change of parameters even in the introduction of new hypothesis. Overall, it is an extremely versatile approach that can be translated into a considerable reduction of time and thus saving of monetary resources.
- Data can be accommodated from different spatial sources such as fieldwork data, remote sensing imagery and secondary data. Again the versatility of the GIS can be appreciated in its flexibility in accepting different sources of data. Basically it means that quality of data input is almost completely dependent on the data quality by itself and not on the format of the data available.
- There is an efficient and increasing access to a huge volume of data, thereby improving the quality of decision and the cost-effectiveness realized on the farm level by optimizing its location and on the public level by optimizing resources allocation.

In aquaculture, the application of GIS is proliferating particularly in the field of planning for aquaculture development. The use of a GIS-based model has already proven to be a powerful approach to assess the suitability and opportunities for mollusks culture as shown in the work carried out by Kapetsky *et al.* (1987). Moreover, aquaculture has benefited significantly from the use of GIS and remote sensing in recent years and these techniques have jointly showed their capabilities in evaluation and assessment of suitable sites for a variety of aquaculture systems (Salam and Ross, 1999).

There is a growing trend towards using GIS for natural resource management worldwide. In the field of aquaculture, GIS can help provide the spatial information that decision-makers need when evaluating biophysical and socio-economic characteristics of a given area. Moreover, GIS has the potential to transform the way in which many aquaculture decisions are made, including optimal site selection and monitoring of existing operations with respect to ecological dynamics. While there has been significant research conducted to illustrate the benefits of using GIS for spatial decision support, many of the efforts to date have remained within the academic domain. There is a need to expand the GIS knowledge via training and education to include decision-makers (end-users), as well as for GIS experts to expand their scope in applications.

In comparison with the manual methods, the use of GIS makes the work time-effective for analyzing and extracting information. GIS can only enhance the decision making process by allowing the aqua culturist, the regulating body and the citizens to make informed decisions about the placement of a venture. Despite the environmental factors appearing acceptable for the placement of a project and despite the acceptance of the regulatory body of the scientific evidence of appropriateness of an area, human factors may neglected the very foundation of science.

GIS models can be based on very large or very small areas, with appropriately different spatial resolutions used for different purposes. Several regional investigations of aquaculture potential have been made, particularly for Africa and Latin America, using relatively simple environmental and resource availability models (Kapetsky, 1994; Kapetsky and Nath, 1997; Aguilar and Nath, 1998). A number of national or state level investigations have been conducted successfully, based on a wide range of data on environment, infrastructure, resource availability and socio-economics (Aguilar and Ross, 1995). Further, characteristics of various attributes could then change over time to determine the probable impacts of changing circumstances, such as the effects of drought, the rise or fall of domestic or world market prices, or the development of additional roads (FAO, 1999).

2. Purpose

In spite of having enough aquaculture resources in Mymensingh district, in cannot able to produce more fish adopting intensive fish culture technique. By using GIS modeling technique, we can develop proper planning for aquaculture and identify the suitable sites, hence, can be able to fill up the domestic demand of fish, create employment opportunity, help to alleviate poverty and increase the source of income of the people in the region. From the above discussion, the present piece of work has been planned to assess the suitability in Mymensingh district for aquaculture potential using GIS as a tool. Thus, the objectives of the study are:

- To establish a spatial model for land-based aquaculture development in Mymensingh district
- To select suitable areas for aquaculture development in the region and
- To adopt sustainable aquaculture and management technique in Mymensingh district by adopting aquaculture practices in those sites.

3. Materials and Methods

3.1. Description of the study area

3.1.1 Geographical position

The study area situated is in the northern side of the country where the climate is tropical. Its location is in between the latitudes 24°15′ and 25°15′ North and 90°05′ and 90°50′ East longitudes (Fig. 1). The area is bounded in the North by India, Northeast by Netrokona and Southeast by Kishorgonj district, South by Gazipur district and in the west by Tangil and Gazipur district and Northwest by Sherpur district. It encloses a surface area of 4,363 sq km. comprising of 12 Upazilla namely Bhaluka, Dhobaura, Fulbaria, Gaffargaon, Gauripur, Haluaghat, Isharganj, Mymensingh Sadar, Muktagacha, Nandail, Phulpurand and Trisal. The area contains Bangladesh Agricultural University, Bangladesh Fisheries Research Institute (BFRI) and Bangladesh Institute of Nuclear Agriculture (BINA). The area is renowned for its fisheries and aquaculture activities.

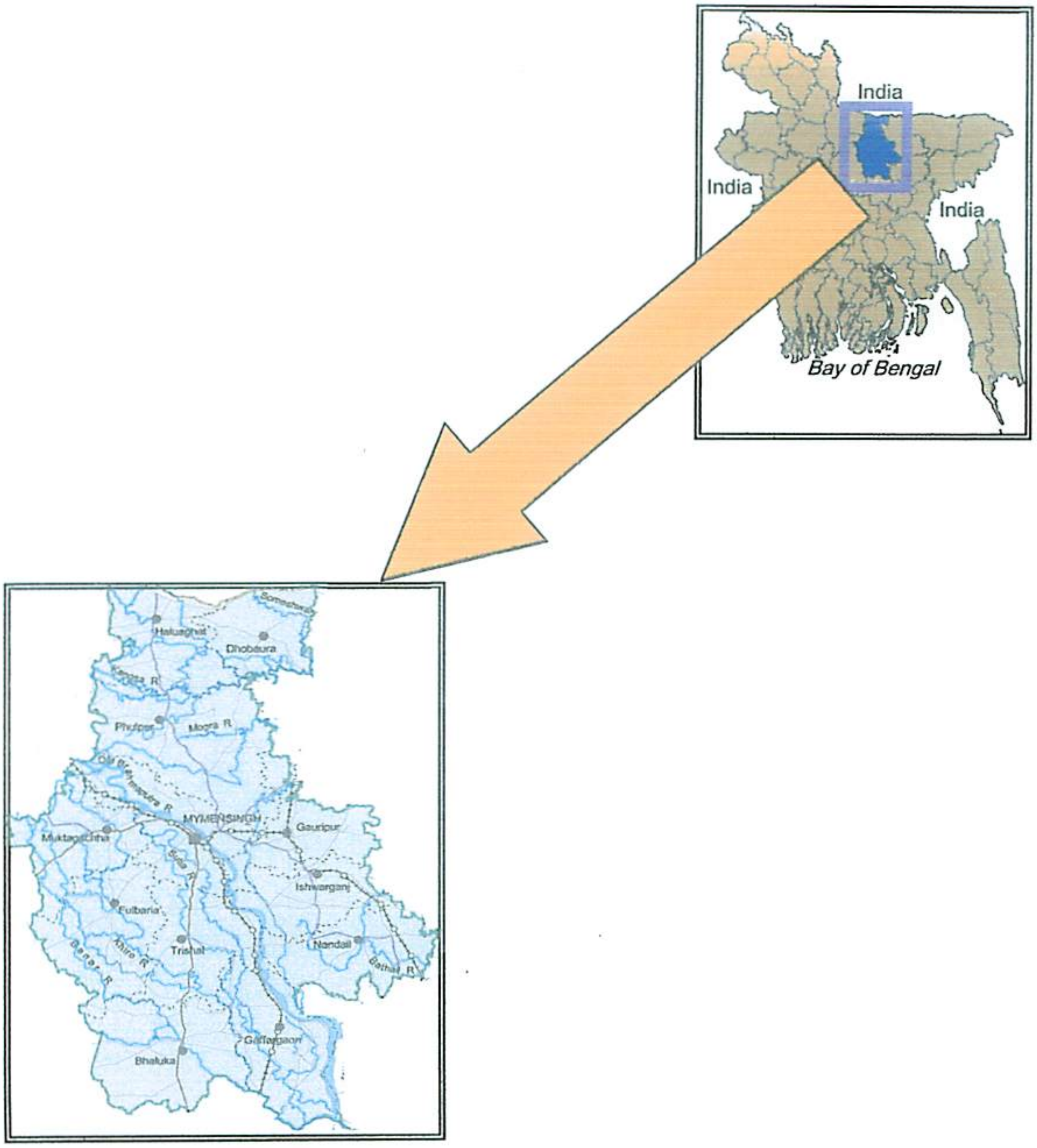


Fig.1. Location of the study area (Mymensingh district) in Bangladesh.

Mymensingh district consists of 12 Upazilla, 146 Unions, and 2,709 Villages. The total population of this district is 4439,017. Among them, 51% male, 49% female. Different religious and tribal people includes Muslim 95% Hindu 4%, Christian 0.75%, Buddist 0.06%, and others 0.21%. Moreover, 0.89% is ethnic population such as Garo, Hajong, Koch and Hadi.

3.2 Analytical framework and constraints

This study can be broadly divided into two categories: a) laboratory based data processing and b) field based data collection. Several types of field data were collected ranging from observation of land use types, vegetation cover, water and soil properties and other parameters to fulfill the objectives of the project which needed to be stored in an organized way for subsequent integration into the GIS databases and the collected field data was processed as quickly as possible to minimize the error in the modeling process.

a) Laboratory based data processing

1. Computer facilities

All laboratory-based data processing were undertaken on a Pentium III desktop computer in the GIS laboratory of the Department of Aquaculture, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh.

2. File and data storage systems

Working with large project requires substantial storage capacity as the project develops and hundreds of new images are generated. However, not all newly produced images are useful, and most of them can be discarded while modelling is done and storage space can then be reused. However, a group of selected images, which are necessary for the persistence of the modeling process, still utilises a lot of hard disk storage space. During the study period most of the data were stored in CD with the help of HP CD writer 9100 series and in Floppy discs.

3. Scanning, Digitizing and Printing facilities

Most of the relevant information for this study was available as printed maps of high quality, so it was easy to distinguish the features on it. The maps were scanned on a HEWLETT PACKARD ScanJet 3200C Scanner. Scanning maps and incorporation into the GIS databases is a very efficient and quicker method of producing GIS layers. Vector layers were produced from the scanned maps using on-screen digitizing facilities in most of the image processing software's such as PaintShop Pro 5, Microsoft Paint and in IDRISI, the GIS software.

4. Maps used in the study

During the study it proved to be difficult to find quality maps to build up the GIS databases. Maps produced by the Soil Resource Development Institute (SRDI) were fair in quality but were not good enough to geo-reference with other maps, as it was 1:1000,000 scale. Infrastructure map was collected from the district Local Government and Engineering Department (LGED) office. However, it was very difficult to obtain some maps, which were published, available in stock, but not normally available for sale except through permission from the defense ministry, as they are confidential or reserved by the military authorities. All these maps were scanned as bitmap images and later incorporated into the GIS databases using import facility of IDRISI.

5. GIS software used in the study

3.5.1 IDRISI for Windows 2.0.

The GIS software used in most of this study was IDRISI for Windows version 2.0. IDRISI is a geographical information and image processing software developed by the Graduate School of Geography at Clark University, Worcester, MA, USA. It is designed to provide professional-level geographic research tools on a low cost non-profit basis for research and teaching. IDRISI currently has a collection of over 100 program modules that provide facilities for input, display and analyzing of geographic data. Modules used in this study will be indicated in capital letters.

Idrisi32 was also used for some parts of this study. It is fully 32-bit software and uses the latest object-oriented development tools and is a considerable advance over IDRISI 2.0. Special facilities are included for environmental monitoring and natural resource management, including change and time series analysis, multi-criteria and multi-objective decision support, uncertainty analysis (Bayesian and Fuzzy Set Analysis) and simulation modeling. TIN interpolation, Kriging and conditional simulation is also offered.

DIGI-EDIT Software was also used for digitizing and editing data. ArcView is the most important GIS software for vector data analysis, which was also used for converting some shape files brought from E-GIS, BARC and WARPO. Some of the tabular data were processed in Microsoft Excel before being imported into IDRISI. In addition, other image processing software such as Paint Shop Pro 5 is also used in the study.

6. Image Manipulation

Image editing and manipulation was an important feature of creation of the databases. In practice, images were manipulated and processed prior to or during the modeling phases carried out in the GIS environment. Among the advantages of pre-treatment or editing of images is the elimination of some features, which are of no interest, while leaving others. An example of this is that all unwanted features in a scanned map such as legends, titles, scales, and text can be eliminated, while leaving only the selected subset of the map area and the thematic polygon features. This editing process is possible in IDRISI, but it is more awkward and time consuming than in Paint Shop Pro 5. Specifically, on-screen digitization in IDRISI has limitations related to the buffer capacity for the vector file being worked on, often leading to the abrupt termination of the program due to insufficient available memory, and resulting in total loss of files in the digitizing process.

7. Geo-referencing of the images and maps used in the study

Geo-referencing refers to the location of an image or vector file in space as defined by a known co-ordinate system. In GIS world it is possible to transfer raster images and vector files from one grid reference system to another. As the map was obtained by scanning process, so the reference system was established as plane automatically. Geo-registration is also known as rubber sheeting or resampling. It is the process of stretching and wrapping an image to fit in a particular grid reference system. Identifying a series of X and Y co-ordinates of two pairs of points that represent the same place within the both new and old co-ordinate system accomplish the resampling (Eastman, 1997). The pairs of X and Y co-ordinates are entered into a correspondence file using the EDIT facility in IDRISI, or alternatively, they can be entered in a spreadsheet such as Microsoft Excel or any text editor. The list is then saved as a text file format, which can be imported into IDRISI.

In this study, a list of 40 points of co-ordinates, which were clearly identifiable both on the LGED map as well as on the soil map, was entered into a correspondence file. These points were typically road crossing or various typical points which are clearly visible in both the maps. The Quadratic resampling was used with the nearest neighbour algorithm. In general, the lowest order of polynomial should be used that provides a reasonable solution since the effect of poor control point specification becomes dramatically worse as the order of equation used increases. An adequate number of control points are needed for the order chosen. Linear requires a minimum of 3, quadratic requires 6 and cubic requires 10 points (Eastman, 1997).

The accuracy of the resampling procedure is measured by its Root-Mean-Square (RMS) error. The RMS is a measure of the variability of measurements about their true values and is estimated by taking a sample of measurements and comparing them with their true values. These differences are then squared, summed and divided by the number of measurements to achieve a mean square deviation. The square root of the mean square deviation is then taken to produce a characteristic error measure in the same units as the original measurements. The RMS error is directly comparable to the concept of a standard deviation.

8. Resolution of image

Resolution refers to the size of the smallest feature that can be determined in an image. It is basically the same as the scale of the image, except that stretching a small image into a bigger one and interpolating the in-between pixels increases the scale of the image, but it cannot increase the resolution since no information is being added. Scale or resolution is usually measured in meters per pixel for raw images and degrees per pixel for map products. Image quality improves with higher resolution, but only up to a certain point, after which increasing resolution simply makes file sizes unmanageable without yielding any visible improvement to the image.

b) Field based data collection

Ideally, a study of this kind needs extensive field survey works to update existing databases, observe land use and for model verification. A major source of such information was the field visit program, which included meetings on site with the district administrative, Fisheries Department, Universities, Research Station, fish farmers, hatchery owners and NGO's. The objectives of the program were to obtain first-hand information, views and experiences. Examination of sites of fish culture activity in the area was also performed. Discussions with officials and scientists from the DOF, processing plants, NGO's and field workers were made. Finally, models were verified during field trips. The sources of collected information are presented in Table 1.

3.3 Spatial manipulation of factors

In order to prepare data for spatial modeling, depending on the origin of the data, the primary data layers could be manipulated in different ways:

Spatial evaluation in IDRISI environment, all the factors needed must be scored positively with respect to suitability, meaning appropriateness according to predetermined conditions and requirements or circumstances. This is a common term in decision-making or allocation situations where tracts of land are to be allocated according to their suitability for one or more purposes. Suitability for a purpose is determined by whether or not certain criteria are met by the piece of land under consideration. The results of such assessment can be presented in the form of a suitability map.

Table 1. The list of collected information, their sources and location.

Data type	Sources of Data	Location
Information about Fisheries resources in Mymensingh district	Department of district Fisheries office and Different of Upazilla Fisheries office in the district.	Upazillas in Mymensingh district (Bhaluka, Dhobaura, Fulbaria, Gaffargaon, Gauripur, Haluaghat, Isharganj, Mymensingh Sadar, Muktagacha, Nandail, Phulpur and Trisal.)
Information about crop production in the area	Bangladesh Agricultural Development Corporation, Mymensingh	Khamarbari, Mymensingh
Information about amount of Fertilizer used	Bangladesh Agricultural Development Corporation Mymensingh	Khamarbari, Mymensingh
Water depth storage data of MPO	Water Resources Planning Organization, Ministry of water Resources (WARPO)	WARPO, Dhaka
Environmental Parameters of NEMAP	WARPO	WARPO, Dhaka
Feeder Type-A of RHD	WARPO	WARPO, Dhaka
Surface water parameters of MPO	WARPO	WARPO, Dhaka
Physiographic Units	WARPO	WARPO, Dhaka
Overall Information about the study area	BANGLAPEDIA National Encyclopaedia of Bangladesh	Dhaka
Statistical Pocketbook of Bangladesh 1997	Bangladesh Bureau of Statistics and Planning Division.	Dhaka
Information about local market in the study area	Local Government and Engineering Department	Mymensingh
Base map of the study area	LGED office	Mymensingh
Soil map of the study area	Soil Resource Development Institute	Dhaka
Underground water depth	Public Health and Engineering Department	Mymensingh

Most of the factors were reclassified using the RECLASS or ASSIGN module according to the requirement. For example, land use maps, which were already classified according to agricultural crops, could be reclassified in terms of aquaculture suitability where highly intensive agriculture land would have a low score for aquaculture because these sites would be likely to have pollution problems from pesticides or herbicides (Kapetsky, 1989).

In some cases a distance range was created using the DISTANCE module. This was applied to factors such as rivers or roads that are commonly represented spatially as either points or lines. For example, to evaluate water availability from a river, a buffer zone was created using the DISTANCE module in IDRISI. Therefore, a range of values was created (1- 4). Those closest to the river were given a score of 4 and the furthest away a score of 1.

Moreover, DISTANCE module was also used to represent the distances from the sources of pollution, such as certain distance from the industries or urban developments in order to avoid or alleviate possible pollution problems in order to establishment sustainable Aquaculture.

3.4 Criteria selected for sustainable aquaculture development

The selection of factors involved in a GIS modeling is very important since they are the basis of the evaluation of potential sites for fish culture in the area. These factors are sometimes called production function (Meaden and Kapetsky, 1991) or criteria (Eastman, 1995). These criteria are of two kinds: factors and constraints (Eastman, 1995). Factors are also known as decision variables or structural variables. On the other hand, a constraint serves to limit the alternatives under consideration. In most cases constraints are expressed in the form of a Boolean map, for example areas excluded (water bodies, settlement, roads etc.) from consideration being coded with 0 and those open as consideration with 1.

Some factors were grouped to form sub-models naturally, such as, a soil sub-model based on, soil texture, soil p^H and land type. One reason for developing sub-models in a decision making process is that MCE can only easily handle a certain number of factors (usually less than ten factors, Ross, 1998) in a particular objective. In overview, fourteen criteria were used to identify the suitable site for aquaculture in Mymensingh district. Table 2 represented the criteria selected for the study.

3.5 Water sources sub-model

When evaluating a site for fish culture, the total land and water resources in the area are the prime determining factors. However, growing demands for water supply day by day for expanding aquaculture industry competes with other water users such as irrigation, industrial uses, navigation, drinking, and for environmental needs for this limited resources (Muir and Beveridge, 1987; Patricia, 1999; Phillips *et al.* 1991).

The amount of water used in fish culture ponds includes the volume used to fill the pond initially and any amount needed to maintain the minimum water level of the pond during the culture period. The usual sources of water for aquaculture can be rainwater, reservoirs, rivers or streams, spring, irrigation canals, surface runoff, and underground. Most farmers in the region depend on rainwater to fulfil their ponds. They culture fish for 4-6 months in a year that is in rainy season. Out of rainy season, they used rivers, khals, beels and ground water as the sources of water. But most of the farm of the study area used underground water for fish culture. So we considered rivers, khals and beels as surface water, rainfall as natural water source and ground water for sustainable aquaculture development in the area. Underground water depth of the study area is low compare to the northern part of the country so it is easy to use. Positions of the deep tub-well were collected from the Public Health and Engineering Department of Mymensingh district office, which included in the modeling. The rainwater used from the average rainfall data from the selected rain station in Mymensingh region. The average amount of rainfall was used as values file to get water source sub-model. On the other hand, the surface water sources are used in the sub-model using the DISTANCE module. The reclassification scheme of water sources shows in Table 3 and Fig. 2 Shows schematic diagram of water sources sub-model for aquaculture development in area.

Table 2. Criteria selected for sustainable aquaculture development in Mymensingh district.

Criteria	Criteria for aquaculture development
Surface water body	Water sources
Underground water	
Rain Water	
Soil p^H	Soil quality
Land type	
Soil texture	
Soil permeability	
Highways Rail ways All weather motorable roads	Infrastructure
Hatchery	
Nursery	
Town-market	Market
Village market	
Rice bran	Agricultural inputs
Wheat bran	
Mustard oil cake	
Animal wastes	
District Fisheries office	Extension support services
Upazilla Fisheries office	
NGOs	
Bangladesh Agricultural University	
BFRI, Mymensingh	

3.7 Soil Sub model

3.7.1 Soil pH

pH is considered as a most important factors in fish culture. Most of the nutrients in the pond water are directly influenced by soil p^H. If the p^H is too high or too low, some nutrients become insoluble, limiting the availability of nutrients to the organisms. It indicates the acidity and alkalinity of water body. Besides indicating hydrogen ion concentration, p^H acts as an index of several environmental conditions, such as (a) free carbon dioxide concentration, (b) dissolved oxygen content, (c) concentration of nutrients, (d) acidity-alkalinity etc.

Six point five to 8.5 p^H ranges are available in most water bodies in Bangladesh. The circum-neutral p^H or slightly alkaline p^H is most suitable for fish culture (Rahman, 1992). pH 6.5 to 9 is suitable for fish culture and p^H more than 9.5 is unsuitable because free CO_2 is not available in this situation (Swingle, 1967). Fish dies at p^H 11 and p^H less than 6.5 reduce fish growth, physiological activities, and tolerance to toxic substances. Diseases can easily attack fish when p^H is less than 6.5. Soil p^H was extracted for this study from the soil map. Table 3 shows the classification of soil p^H in the study area.

Table 3. The classification scheme for different factors for aquaculture development in Mymensingh district

Criteria	Very suitable	Moderately suitable	Marginally suitable	Currently unsuitable
Underground water	<100 m.	100 – 200 m	200- 300	300>
Average rainfall	>2400 mm	2200 – 2400 mm	2000 – 2200 mm	<2000mm
Surface water sources	>450 m	450 – 550 m	550 – 650 m	< 650 m
Roads	<1000 m	1000 – 2000 m	2000 – 3000 m	> 3000 m
Hatchery	>100 kg	50 – 100 kg	30 – 50 kg	> 30 kg
Nursery	>100 lack	50 – 100 lack	30 – 50 lack	> 30 lack
Soil pH	Neutral to light alkaline	Light acidic to neutral and light alkaline to neutral	Moderate acidic	Highly acidic and Highly alkaline
Soil texture	Medium high land	High land	Medium lowland	Lowland
Soil permeability	<12cm per day	12-305cm per day	> 305cm per day	Very highly permeable
Rice bran	>300 mt. ton	250 –300 mt. ton	200–250 mt. ton	<200 mt. ton
Wheat bran	>300 mt. ton	250 – 300	200 –250	<200
Mustard seed	>500 mt. ton	400 – 500	300 -400	<200
Animal wastes	>7 mt. ton	6 – 7 mt. ton	4 – 6 mt. ton	< 4
Feed industries	<15 km.	15 – 25 km.	25 – 40 km.	> 40 km.
Town Market	<15	15- 20	20 - 25	> 25
Local Market	< 10	10 – 15	15 - 20	>20
NGO support	>20	15 – 20	10 - 15	< 10
Government support	< 10 km	10 – 15 km	15- 20 km	> 20 km
BAU and BFRI support	< 25 km	25 – 50 km	50- 75 km	>75 km

3.7.2 Soil texture

The soil texture is a very important aspect to be considered for aquaculture site selection, development and management. This is particularly the case in pond aquaculture, where soil quality has a great influence on construction and maintenance the costs, and productivity. It is also important in selecting sites and developing designs for additional components such as water supply channels. Excessive seepage often results from improper site selection; therefore, soil properties should be clearly investigated and identified prior to site selection (Coche and Laughlin, 1985 and Boyd, 1990).

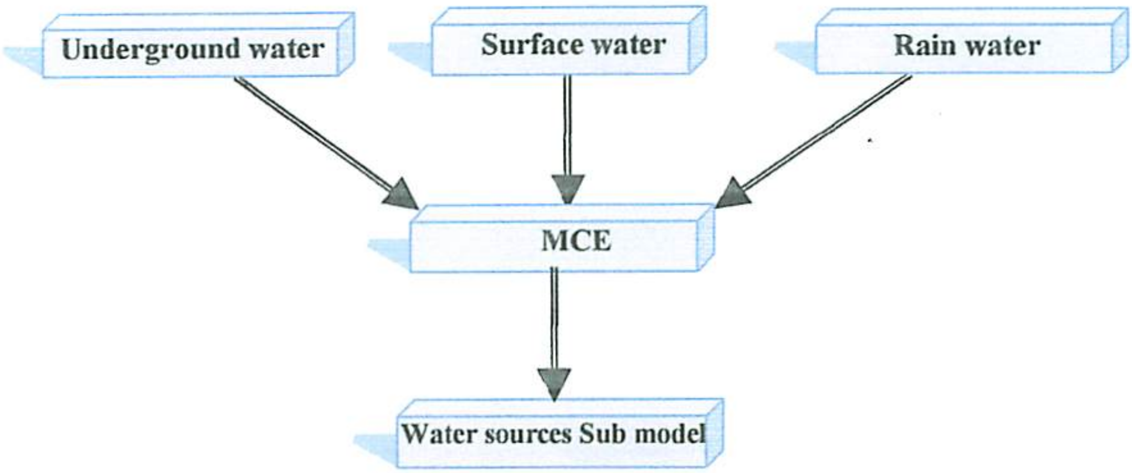


Fig. 2. Schematic diagram of water sources for aquaculture in the study area.

In order to identify suitable areas for pond construction, two criteria were chosen: surface soil texture (<20 cm) and sub-surface soil texture (>80 cm). Coche and Laughlin (1985) include three texture classes: coarse, medium and fine in their soil classification and they identified the best soils for fishpond construction.

Soil quality is very important factor for fish culture. Soil possesses a number of essential nutrients that enhances the primary productivity of fishpond. Water quality especially chemical qualities, almost completely depends on the quality of soil of the ponds. Generally good fish production may be expected from a pond constructed in a land, which is fertile for crop production. It is well known to all the essential nutrients; which are required for overall productivity of water bodies come from the soils. The best pond bottom soil is that where decomposition of organic matter is rapid and soil-water interaction is continuous and favourable to release essential nutrients from bottom-mud. Table 3 shows the classification of soil texture in the study area.

3.7.3 Soil Permeability

Permeability is the physical parameter to determine of the soil quality. The soil, which is highly permeable, those are not suitable for pond construction. So, the determination of soil permeability is very important before establishment of an aqua farm. Water leaching from the ponds in dry season due to high permeable soil and evapotranspiration resulting economic loss in fish culture. The study area occupies generally smooth relief of broad ridges and shallow basins. However, more irregular relief occurs locally, especially close to the old Brahmaputra River. There erratic occurs shallow fine sandy loams and silt, loams overlaying sand, specially in Ishargonj and Nandail Upazilla of the study area. Proximity ranges of permeable soils in Mymensingh district for sustainable aquaculture development are given in Table 3.

3.7.4 Land types

One third of the land becomes flooded every year in rainy season in Bangladesh. The land classification of Bangladesh is (i) High land (less than 2-3m inundation), (ii) Medium high land (less than 1m inundation), (iii) Medium low land (1-2m inundation), and (iv) Low land and very low land (more than 2m inundation). The high land can be cultivated all the year round but water-holding capacity in those ponds all through the year could be one major problem. The medium high land can be cultivated almost all over the year. It is suitable for pond construction as seepage of water will be moderate and normal flood cannot affect the culture operation. Medium low land can be cultivated between November-May with the irrigation. Special design of ponds construction, management or maintenance may overcome the limitations. Non-availability of irrigation water during this time is also a limiting factor for this land. Lowland is unsuitable for pond construction. During rainy season, pond will go under water and will not be possible to keep the fish in ponds and farmers will be loser. Mymensingh normally under flood free zone because the elevation of the land is 2-3m high from the mean sea level. Table 3 shows the classification procedure for land types and Fig. 3 shows the schematic diagram of soil sub-model for sustainable aquaculture development in Mymensingh district.

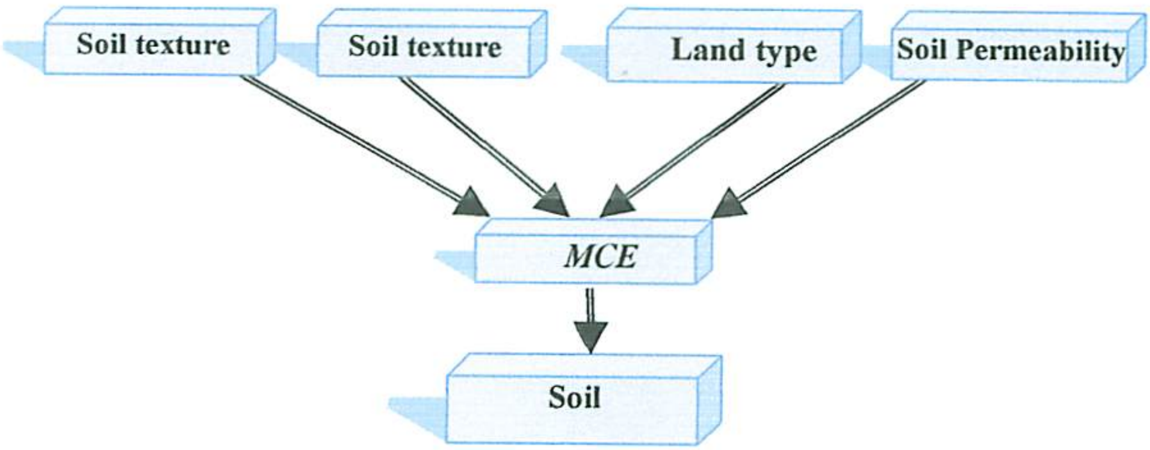


Fig. 3. Schematic diagram of soil sub-model for sustainable aquaculture development in Mymensingh district.

3.8 Infrastructure

Infrastructure is an important criterion for the development of aquaculture in any particular area. For the purposes of this study, the major infrastructure factors were considered to be:

- Highways, all weather motorable roads and railways for transportation networks.
- Available hatchery for seed supply
- Available nursery for fingerling supply

3.8.1 Road networks

Roads required to transport products to processor and markets and to receive the goods and supplies necessary for fish culture operation. Proximities are important in two ways: site development costs and culture operation costs. Close proximity to a road or landing center is mean that site development costs for road building will be less than for a more distant site. Likewise, close proximity to a facility for processing and marketing aquaculture products, to a large town for supplies or to a feed mill mean that transport costs will be less than from a distant place. For this study, highways, railways and all weather motorable roads were considered. The roads were derived from LGED map and E-GIS, WARPO and BARC data. Proximity was calculated using the DISTANCE module and classification shown in Table 3.

3.8.2 Hatchery

Hatchery is a place, where fish seeds are produced for stocking in the ponds. It is the important unit for development of sustainable aquaculture in any particular area. The amount of fry production used as values file with the help of GIS software prior to modeling process. Proximity was calculated using the ASSIGN module and then classified which shown in Table 3.11 for sustainable aquaculture development in the Mymensingh district.

3.8.3 Nursery

Nursery is a place, where fish seeds are nurse from fry to fingerling in small ponds. Nursery can supply good quality fingerlings to the fish farmers. Nursery is also economically viable due to high growth rate of fry. Production of fingerlings is used as values file, with the help of GIS software for modeling. Proximity was calculated using the ASSIGN module and the proximity was then classified as shown in Table 3 for aquaculture development in Mymensingh district. Fig. 4 shows the sequence of infrastructure sub-model development for aquaculture development.

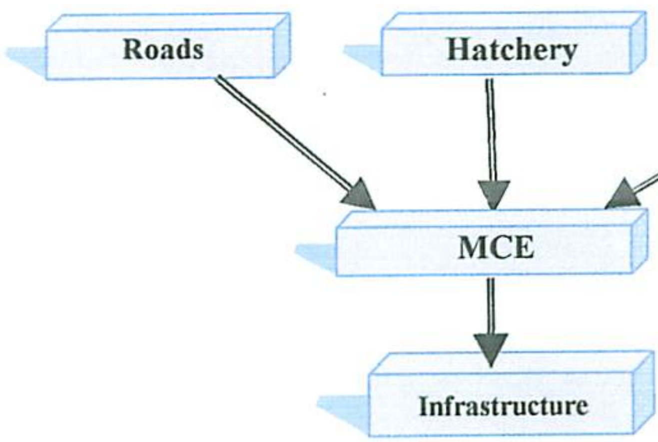


Fig. 4. Schematic diagram of infrastructure sub-model for sustainable aquaculture development in Mymensingh.

3.9 Input sub-model

Input include agricultural by products and animal wastes. The quality and quantity of input affects the output of the aquaculture. The available inputs in the study area that are rice bran and wheat bran used as fish feed and animal wastes used as organic fertilizer. Mustard oil cake is an important input but less available in the study area. Feed industries also important for development of sustainable aquaculture in the area.

3.9.1 Rice production

By product from the rice (rice bran) is more import ant than wheat and oil seed because fish farmers usually use rice bran into the fishpond directly and available in every household. For example, almost every household has more or less rice, which produces rice bran, or they can collect it easily from their surroundings. The classification scheme for rice production is shown in Table 3.

3.9.2 Wheat production

Wheat bran is also an important feed ingredient for fish culture. Wheat bran is comparatively cheap, locally available and easily applicable to the fishpond. In all the study area wheat production is more or less same. Wheat production data was collected from the agriculture office, which used to values file and later it was reclassified as wheat production per sq. km. Table 3 shows the data interpretation and scoring of wheat production in study area.

3.9.3 Mustard oil cake production

Mustard oil cake is also an important feed ingredient for fish culture. Mustard oil cake is used in fish feed as protein source. Animal protein sources are scarce in our country. Animal protein sources can be replaced by mustard oil cake resulting feed cost decreases. The classification scheme for mustard production is shown in Table 3.

3.9.4 Animal wastes production

Animal wastes are widely used in small-scale and commercial fish farming. The objective of livestock wastes estimation is to predict the amount of manure available in the area, which could be used for fishpond fertilization in the region. Number of livestock per square kilometer is used as a surrogate measure of manure availability. The number of cattle, buffalo, sheep, goats, poultry and duck were collected from the District Livestock office. The total amount of manure produced daily by various animals depends mainly on their live weight. The wastes data were used to create values file and later it was reclassified according to production per sq. km. Table 3 shows the data interpretation and scoring of wastes production in study area.

3.9.5 Feed Industries

There are four commercial feed industries available in the study area. Besides that small scale feed meal also present in the study area. If the feed industries are situated near the farm area feed transportation cost will be reduced. The location of the commercial feed industries of the study area are digitized from LGED map and used in modeling. Proximity was calculated using the DISTANCE module. Proximity ranges for feed industries given in Table 3 and Fig. 5 shows the sequence of input sub-model development in the study area.

3.10 Market sub-model

Well-established marketing channel is highly desirable for marketing the products amongst the consumers. All the local and town markets are more or less equally important for marketing fish due to its nature. Marketing channel depends with the transport facilities in the region. Two types of market such as local and town market are considered in the study. Location of the town markets were digitized as vector file and converted into raster image that is later incorporated into the modeling process. On the other hand, the number of local market put in a values file which then used in sub model with the help of ASSIGN module. The market proximity is shown in Table 3 and Fig. 6 shows the sequence of market sub model development in the study area.

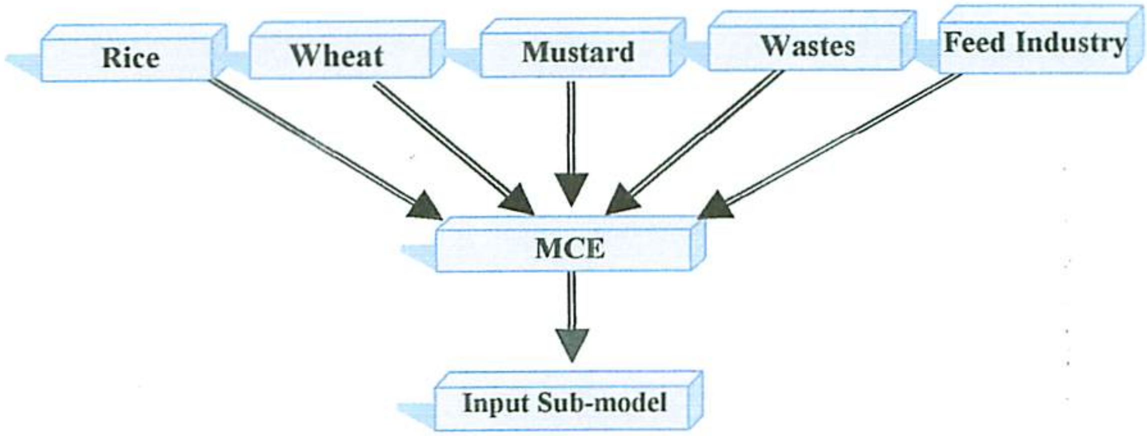


Fig. 5. Schematic diagram of input sub-model for sustainable aquaculture development of in study area

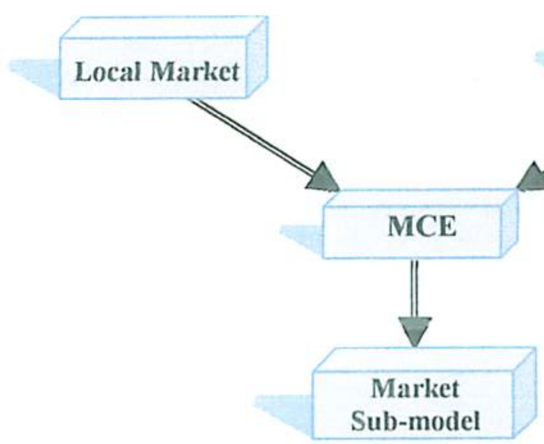


Fig. 6. Schematic diagram of market sub-model for sustainable aquaculture development in study area

3.11 Support sub-model

Support services were designated as the extension support services and other help, which farmers can obtain from NGO, Government offices, Research station and Bangladesh Agricultural University, Mymensingh.

3.11.1 Support from NGO

Several NGOs are working in the country with the vision that they can provide a better life for under-privileged and marginalized communities of Bangladesh society and a strong and effective independent sector to help the farmers to achieve it (ADAB, 1998-99). Different sectoral NGO networks were formed on different issues such as, women development, environment, water and sanitation, education, aquaculture, fisheries, land reform etc. Data interpretation and scoring is shown in Table 3 and Table 4 shows the weights given to the NGOs according to their manpower and working activities. Fig. 7 shows the strength and range of support provided the farmers by different NGOs.

Table 4. Scoring of NGOs

Name of the NGOs	Score
BRAC	10
CARE	10
PROSHIKHA	10
Gramin Bank	8
ASA	8
Gono Sastha Sangastha	7
Others	5

Scores were calculated according to the working components such as manpower, networks, aquaculture activities, training, credit facilities etc.

3.11.3 Universities and Research stations

In the past, the sole function of the universities was simply to teach students but today universities perform many tasks other than teaching and research. Universities increasingly play an explicit role in contributing to economic and social development in the country to bring economic and social changes in our society. On the other hand, the research stations are implementing many of programs to transfer new technology to farmers' in collaboration with the Department of Fisheries (DOF) and Bangladesh Agricultural Research Council (BARC). This transfer occurs through training the extension workers, organisation rallies arranging, workshops on fish culture, fish nurseries, mini hatcheries, integrated fish farming, fish processing, shrimp and prawn culture. The Bangladesh Agricultural University (BAU) and BFRI situated in the study area. Farmers are influenced by the activities done by these two organizations to fish culture. The location of BAU and BFRI digitized from the LGED map of study area and reclassified according to the suitability ranges shown in Table 3 and Fig. 8 shows the sequence of support sub-model development in the study area.

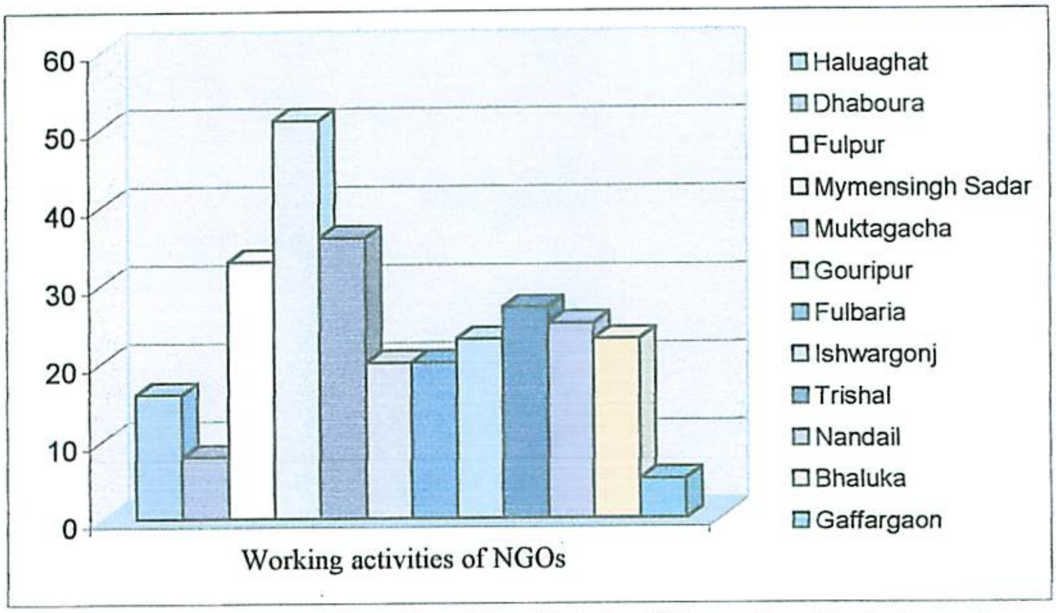


Fig. 7. Ranges of support activities offered by NGOs in different Upazilla in the study area

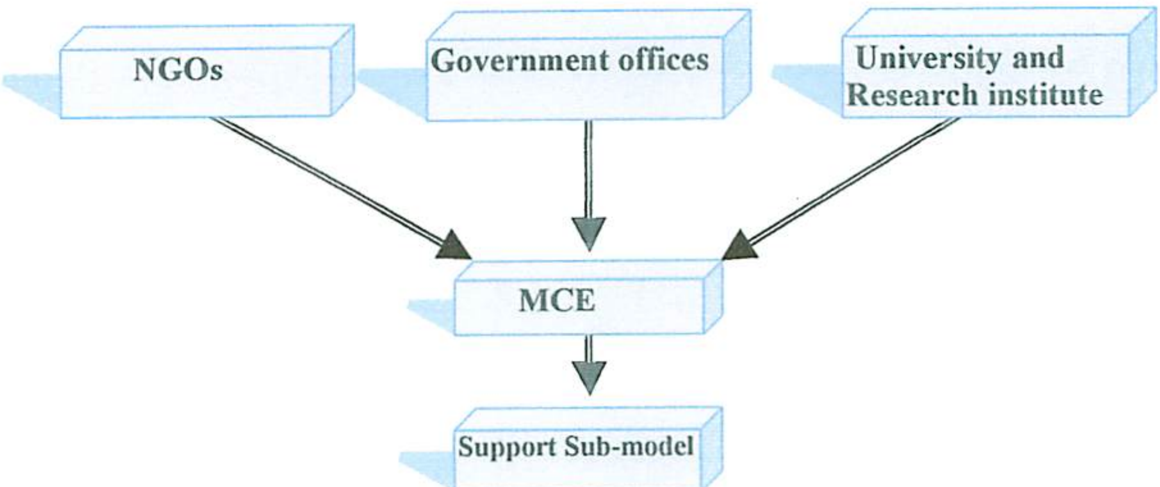


Fig. 8. Schematic diagram of support sub-model for development of sustainable aquaculture in study area.

3.12 Weighting procedure and Multi-Criteria Evaluation (MCE)

In order to determine potential sites for sustainable aquaculture development in the study area, six sub-models were developed. After the sub-model development, it was necessary to establish the relative importance of the sub-models. The weighting of the sub-models were based on the pair-wise comparison matrix developed by Saaty (1977).

The comparison concerns the relative importance of the criteria involved in determining the suitability for stated objective. The ratings are systemically scored on a 17 –point continuous scale from 1/9 (less important) to 9 (most important). The sum of all the factors after weighting will be 1. The weights are then used in MCE module potential site for aquaculture development in IDRISI.

MCE is a method for combining data according to their importance to make a decision on a certain place (Heywood *et al.*, 1995). MCE methods involve qualitative and quantitative weighting, scoring or ranking of criteria to reflect their importance to either a single or a multiple set of objectives (Eastman *et al.*, 1993).

Factors are combined in the form of a weighted linear combination. The basis of this calculation is shown in the following equation.

Suitability (S) = $\Sigma (W_I X_I)$

Where, S = Suitability, W_I = Weight of factor i, and X_I = Criterion score of factor i.

Due to the different scales upon which criteria can be measured, it is necessary that factors needed to be standardized before their combination in the formula above. All factors have to be positively correlated with the suitability.

Using the Saaty's weighting procedure, six sub-models were developed. Finally, a system-oriented model was generated for sustainable aquaculture development by using different combinations and weighting of the modules previously created. To illustrate the approach, sub-models were used to the final matrix (Table 6). According to Saaty a matrix with a consistency ratio greater than 0.10 should be re-evaluated. The weights were then used in the MCE module to show potential sites for fish culture in the study area. Finally constrains were incorporated along with the six sub models during MCE operation which is Boolean in nature and serve to exclude some areas from considerations while allowing other areas which are appropriate for fish culture. Fig. 9 shows the schematic diagram of finding suitable site for aquaculture development in the area.

Table 5. Pair wise comparison matrix to show the relative importance of sub-models (numbers show the rating of the row factor relative to the column).

Factors	Water	Soil	Infrastructure	Market	Input	Support	Weight
Water	1						0.3825
Soil	1/2	1					0.2504
Infrastructure	1/3	1/2	1				0.1596
Market	1/4	1/3	½	1			0.1006
Input	1/5	1/4	1/3	1/2	1		0.0647
Support	1/6	1/5	¼	1/3	1/2	1	0.0428

Consistency ratio = 0.02; Consistency is acceptable

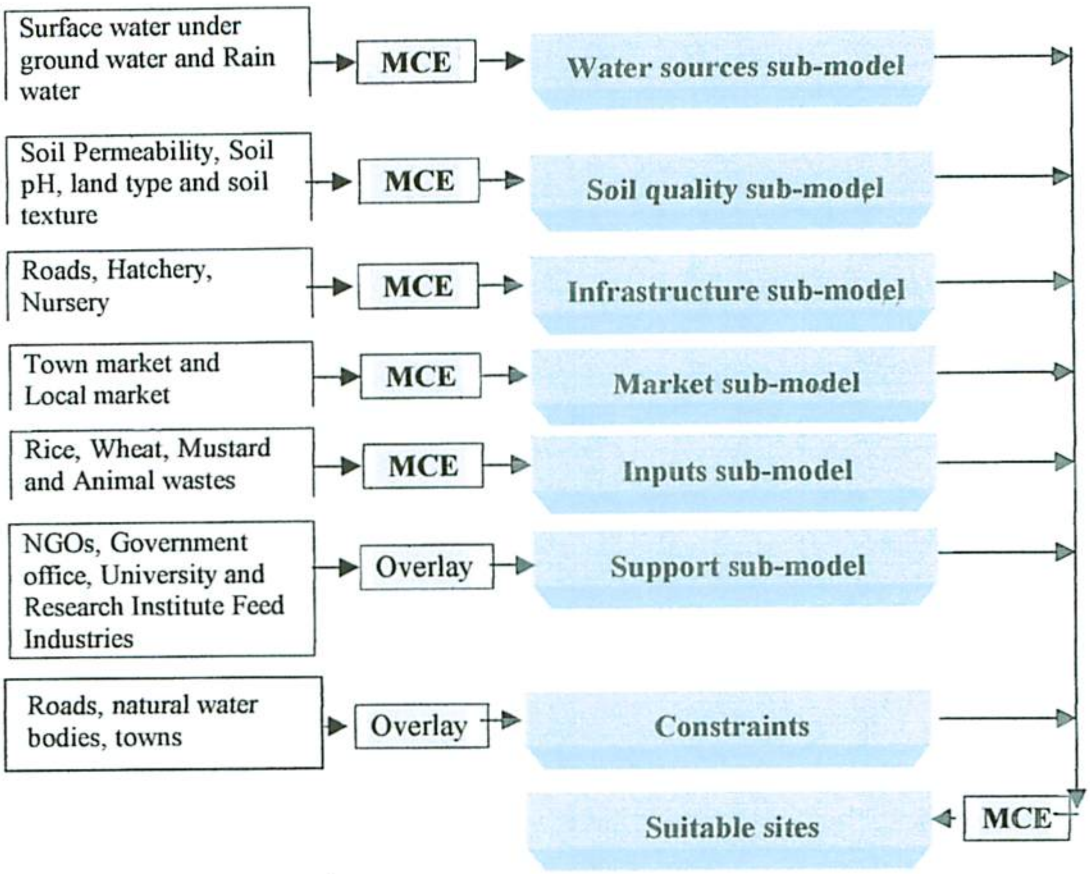


Fig. 9. Shows the integration of six sub-models and constraints for potential in the study area.

4. RESULTS

At first reclassified image is made for each criterion and sub-models formed through integration of reclassified images of the criteria. Then the sub-models are used in the final analysis. The amounts of reclassified potential areas in each sub-model are summarized in Table 6.

Table 6. Percentage of potential area for sustainable aquaculture development in Mymensingh district

Name of sub-models	Very suitable (%)	Moderately suitable (%)	Marginally suitable (%)	Currently unsuitable (%)
Water sources	73	20	4	3
Soil quality	2	57	39	2
Infrastructure	55	21	22	2
Market	79	20	1	0
Agricultural input	22	36	32	10
Support	25	74	1	0

4.1 Results of water sources sub-model

Water sources sub-model consists of surface water, underground water and rainfall, which illustrated the availability of water for sustainable aquaculture development in the area. Fig. 10 to 13 showed the available water in the study area. Image interpretation showed that 73% and 20% areas are very suitable and moderately suitable for aquaculture respectively. This sub- model showed that most of the area is very suitable. On the other hand, only 4% area is marginally suitable and 3% area is unsuitable for aquaculture development in the study area.

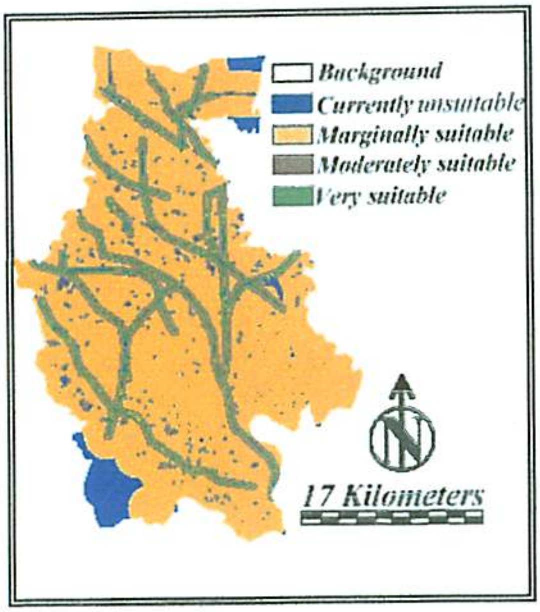


Fig. 10 surface water in the study area

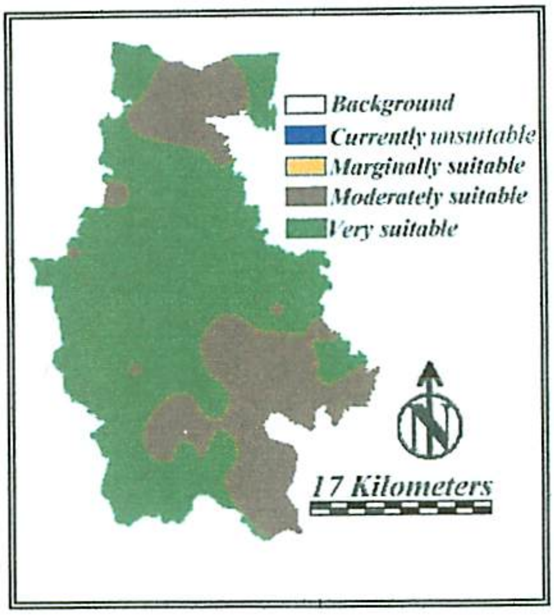


Fig. 11 underground water in the study area.

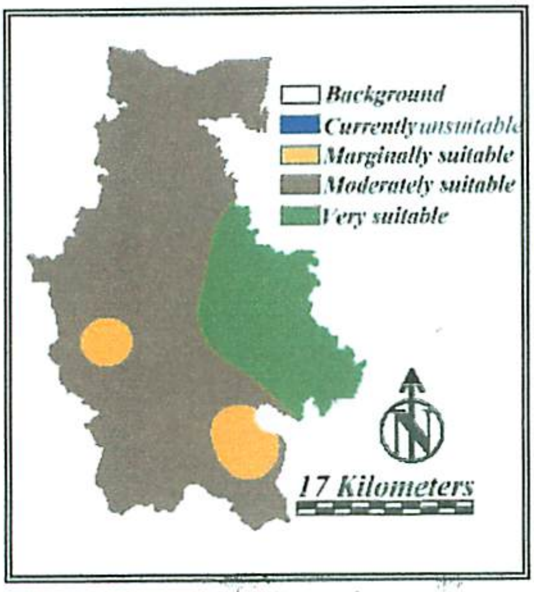


Fig. 12 rain water in the study area.

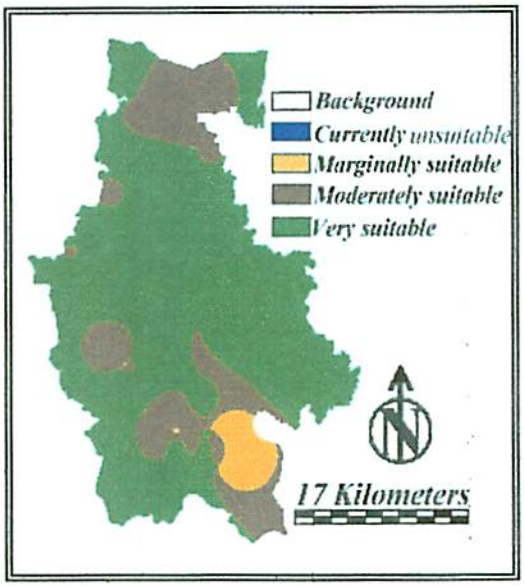


Fig.13 Water sources sub-model for sustainable aquaculture in the study area.

4.2 Results of Soil sub-model

Soil texture, soil pH, soil permeability and land types together constituted soil sub-model (Fig. 14 to 18). In this sub-model soil permeability has the highest amount of very suitable area in comparison to other three categories. Marginally suitable category is completely absent in soil permeability reclassified image. Most of the lands are under very suitable category in the soil permeability image. On the other hand, 12% areas are currently unsuitable which are situated at the south-western part of the area. In soil texture image, all the four categories of suitable land are present, among them most of the land are under moderately suitable category. Whereas, only 3% area is very suitable for fish culture, 53% of the area is under moderately suitable and 35% area is currently unsuitable for sustainable aquaculture development potential in the study area. In land type image also represents all the four categories of land. Among them most of the land is moderately suitable (57%) and 34% land is very suitable for fish culture. Soil pH image shows that only 2% land are very suitable and most of the land is under moderately suitable (81%) category. From the out come of soil sub-model (Fig. 18) most of the area is under moderately suitable (57%) and marginally suitable (39%) categories. On the other hand only 2% area is very suitable for sustainable aquaculture development in the study area.

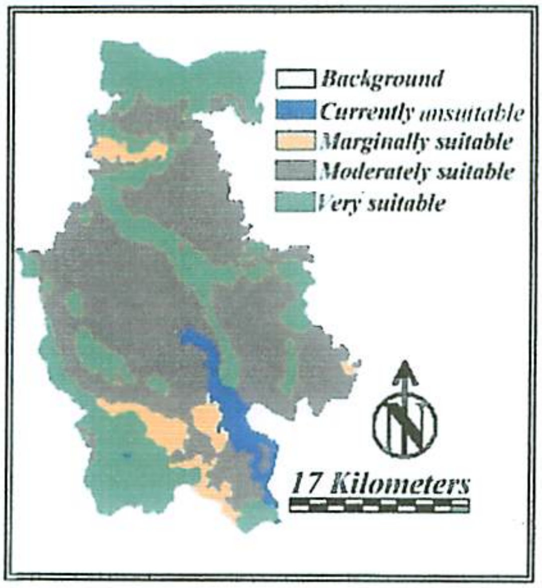


Fig. 14. Land types in Mymensingh area.

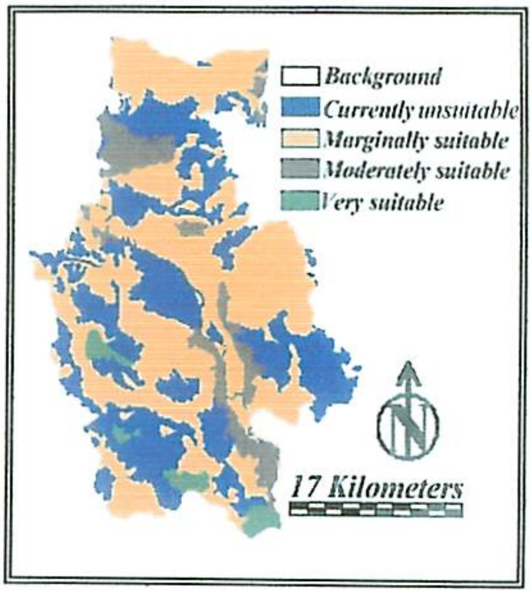


Fig. 15. Soil texture of Mymensingh district

4.3 Infrastructure sub-model

Highways, railways and all weather motorable roads are considered as road networks. Hatcheries and nurseries are also considered as fish seed sources in the study area to develop the sustainable aquaculture. All the above criteria were constituted the infrastructure sub-model (Fig. 19 to 22). In the sub-model reclassified image of nursery ponds represented 69% very suitable land and unsuitable area is completely absent in the image. Hatchery image also represented that the most of the area is under very suitable and moderately suitable category in the study area. Moreover, it is easily comprehensible that 55% area is under very suitable category for infrastructure sub-model, which is scattered along the roadside in the study area. On the other hand, 21% area is under moderately suitable, 22% area is under marginally suitable and only 2% area is currently unsuitable in the study area to develop sustainable aquaculture. Fig. 22 shows the infrastructure sub-model in the study area.

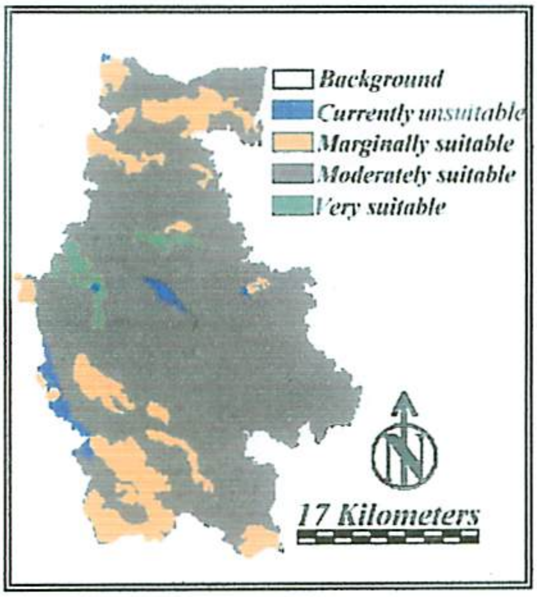


Fig. 16. Soil pH of Mymensingh district

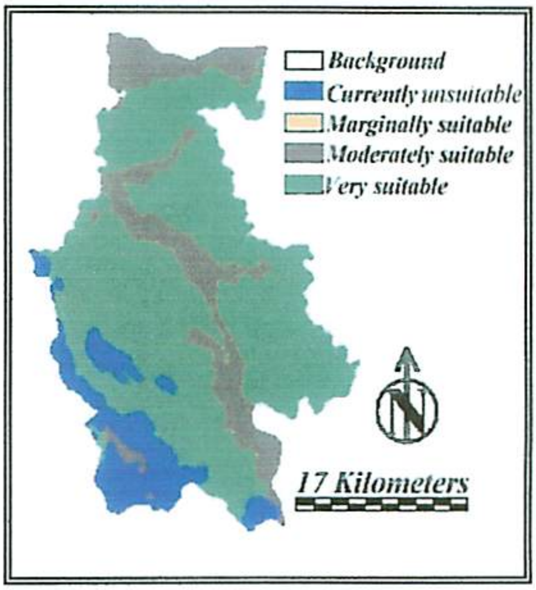


Fig.17. Soil permeability in Mymensingh district.

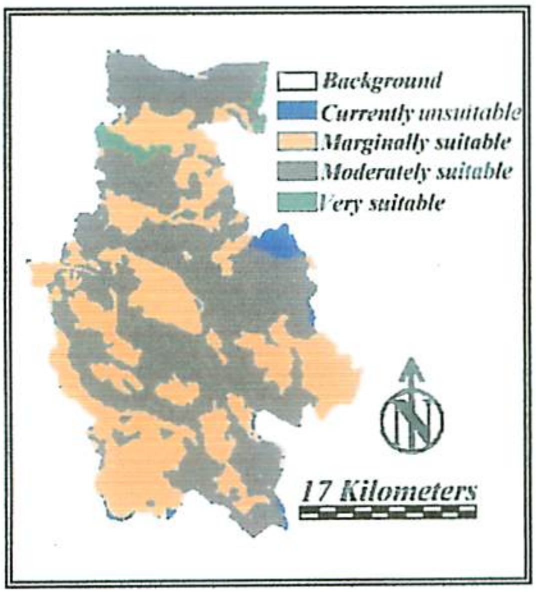


Fig. 18. Soil quality for aquaculture potential in Mymensingh area

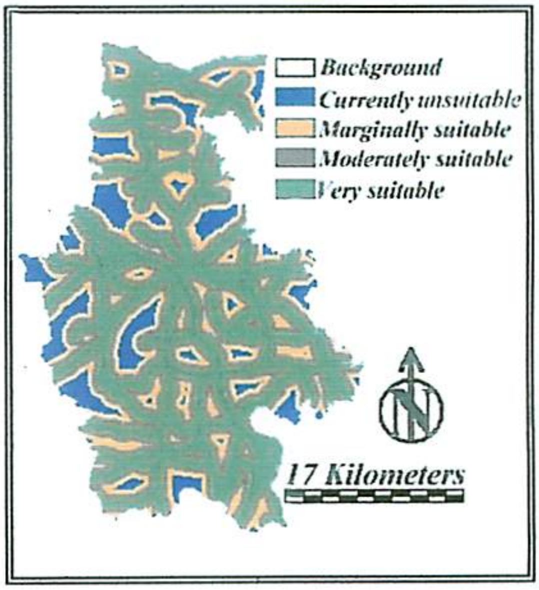


Fig. 19. The highways, railways and all weather motorable roads in Mymensingh area

4.4 Market sub-model

The ranges of town market and local market, together constitute market sub-model (Fig. 23 to 25). In the market sub-model in which 79% of the area is under very suitable category for market potential for fish culture, which is encircled around the Upazilla town. However, 21% of the area is moderately suitable, which is adjacent to the very suitable area. Market sub-model also represented that marginally suitable and currently unsuitable categories are completely absent for development of sustainable aquaculture in the study area.

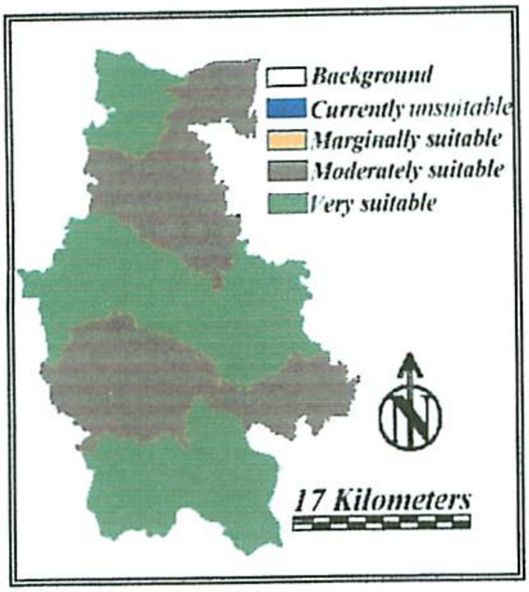


Fig. 20. Intensity of hatchery in Mymensingh region

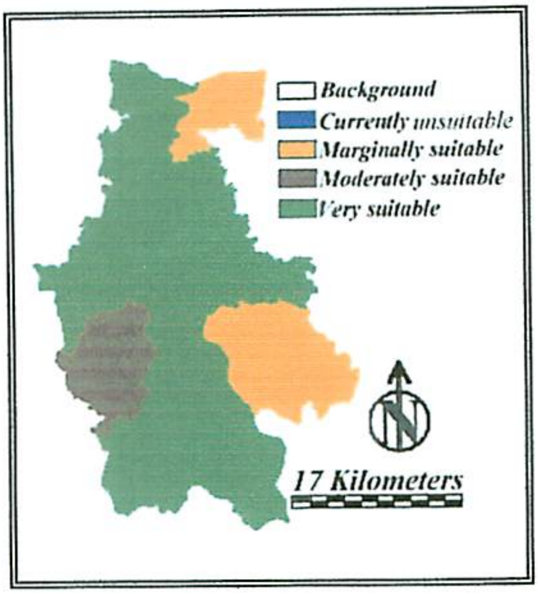


Fig. 21. Intensity of nursery ponds in Mymensingh region

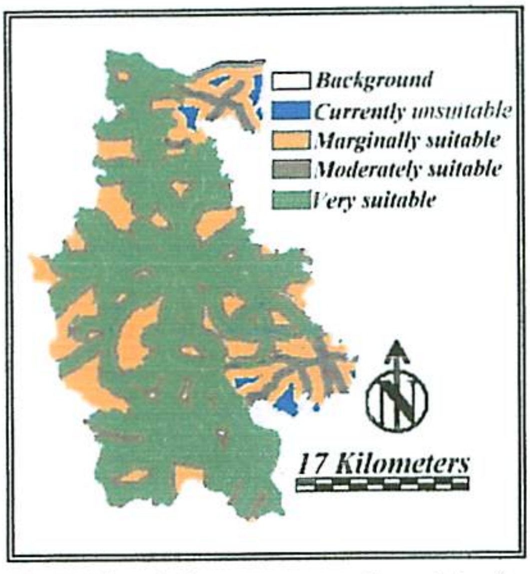


Fig. 22. Infrastructure sub-model for sustainable aquaculture development in Mymensingh region.

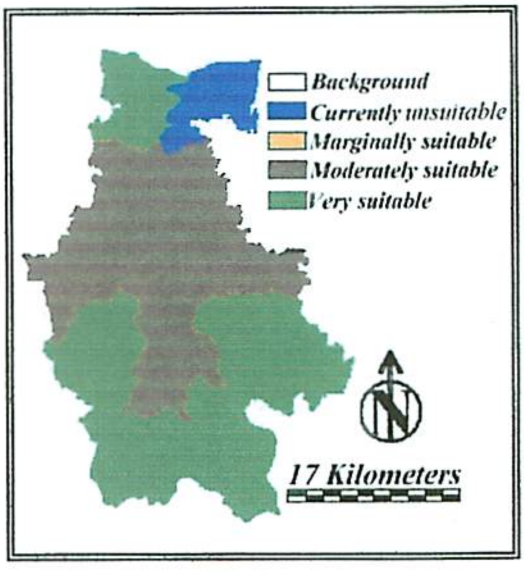


Fig. 23. Intensity of local market in Mymensingh district

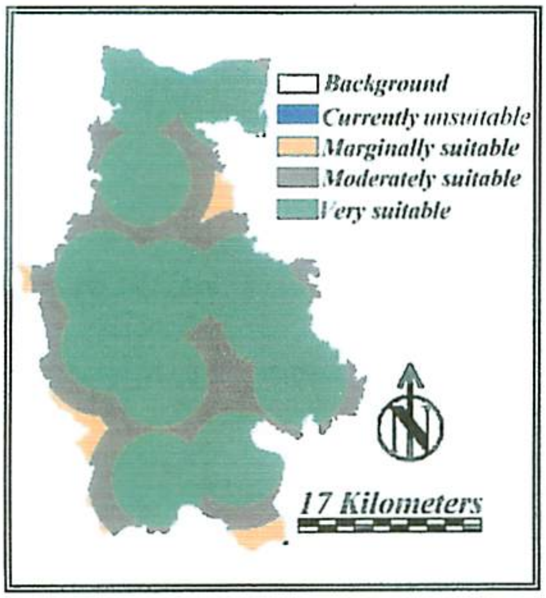


Fig. 24. The town market intensity in Mymensingh region

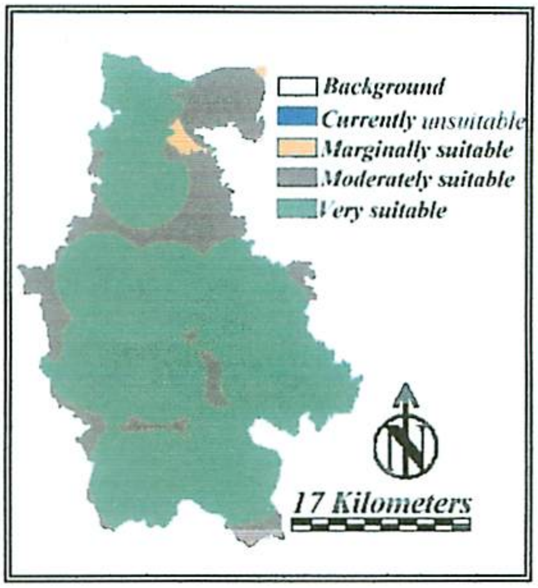


Fig. 25. The market sub-model for sustainable aquaculture development in the Mymensingh district

4.5 Input sub-model

Inputs include agricultural by products, animal wastes and feed industries. The available inputs in the study area are rice bran, wheat bran, and mustered oil cake, which used as fish feed and animal wastes that used as organic fertilizers. Fig. 26 to 31 shows the reclassified image of rice, wheat and animal wastes production, which all together constituted input sub-model. There is not much area in very suitable and moderately suitable category for wheat production in the study area. Most of the land (92%) is under currently unsuitable category and only 8% area is marginally suitable for wheat production. Reclassified rice production image represented that 49% area is very suitable and rest of the land area is under moderately (26%) and marginally suitable (26%) categories. Mustered oil cake production image shows that only 20% area is marginally suitable and rest of the land is under currently unsuitable for development of sustainable aquaculture in the study area. The reclassified image of feed industries shows that most of the area (92%) of the Mymensingh district is under very suitable and rest of the land falls under moderately suitable category. The marginally suitable and currently unsuitable categories are completely absent for fish culture potential site selection area. Wastes production image also represented that 21% area is under very suitable category, only 7% area is moderately suitable and rest of the area shared by marginally suitable (38%) and currently unsuitable (34%) categories for development of sustainable aquaculture in the study area. Out come of the combined input sub-model (Fig. 31) represented that 22% area is under very suitable for fish culture. It is also shows that 36% area is moderately suitable, 32 area is marginally suitable and only 10% area is under currently unsuitable categories for development of sustainable aquaculture in the study area.

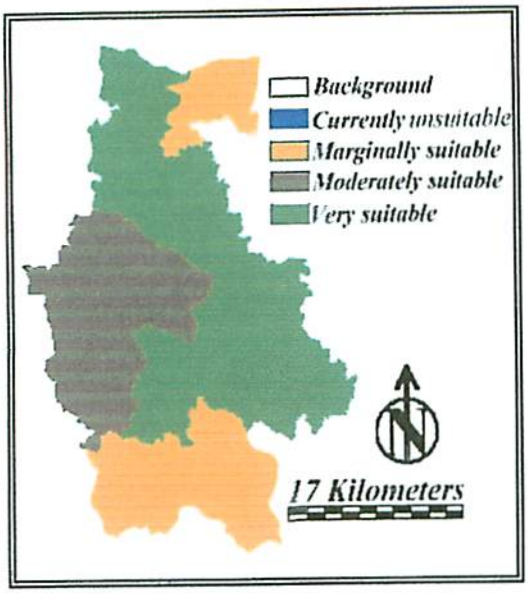


Fig. 26. Rice production in Mymensingh area

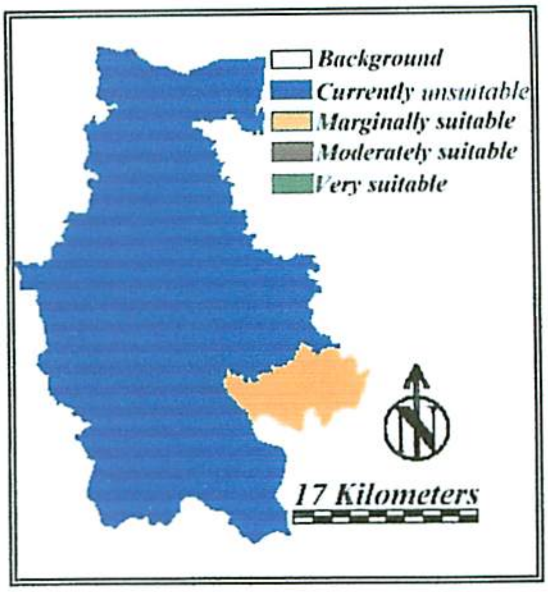


Fig. 27. Wheat production in Mymensingh area

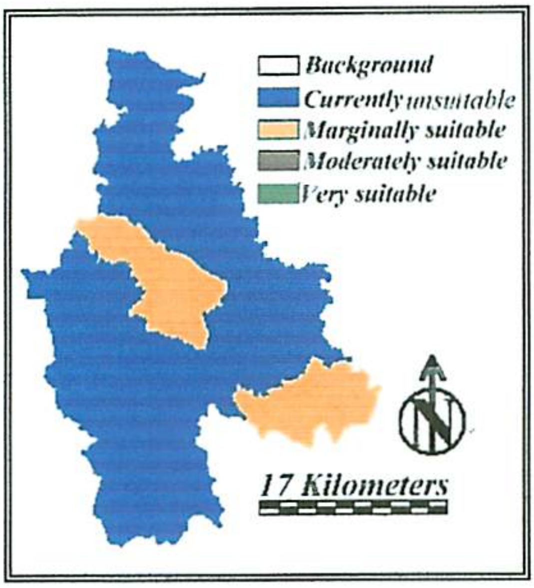


Fig. 28. Mustard oil seed production in Mymensingh area

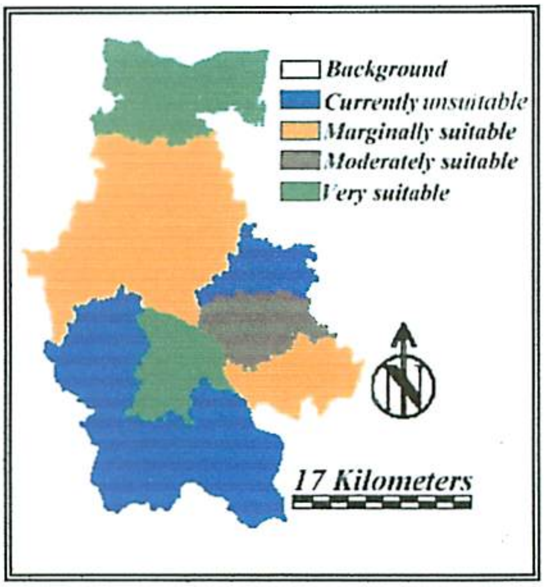


Fig. 29. Available animal wastes in Mymensingh area

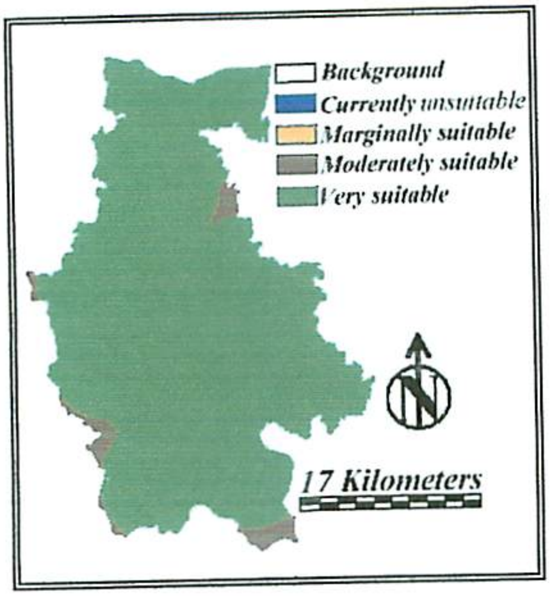


Fig. 30. Feed industries range in Mymensingh area

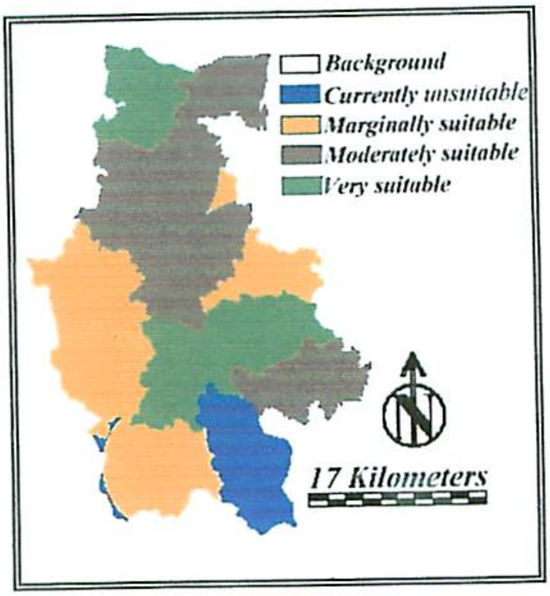


Fig. 31. The input sub-model for sustainable aquaculture development in the Mymensingh district.

4.6 Support sub-model

Fish farmers are getting support from different types of organizations. NGOs are helping fish farmers directly through providing loan and technical support. Fig. 32 to 35 shows the support ranges of NGOs, Government fisheries offices and University and research institute that all together constituted support sub-model. It is clear that most of the area is very suitable (80%) where only 4% of the area is under moderately suitable and 16% area is under marginally suitable category. Currently unsuitable category is completely absent in the study area for the study.

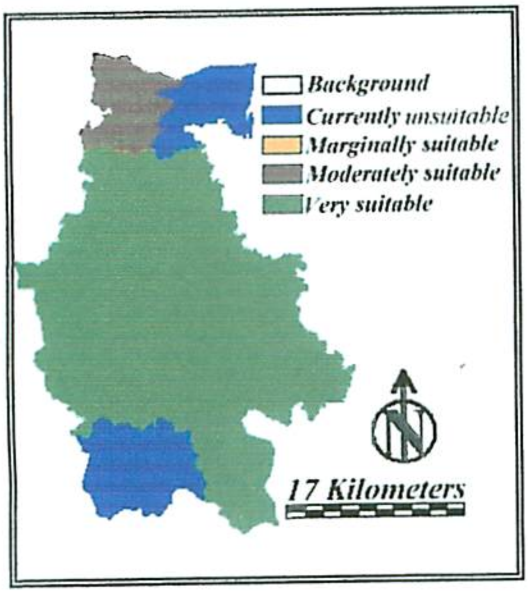


Fig. 32. The NGO support ranges in Mymensingh area

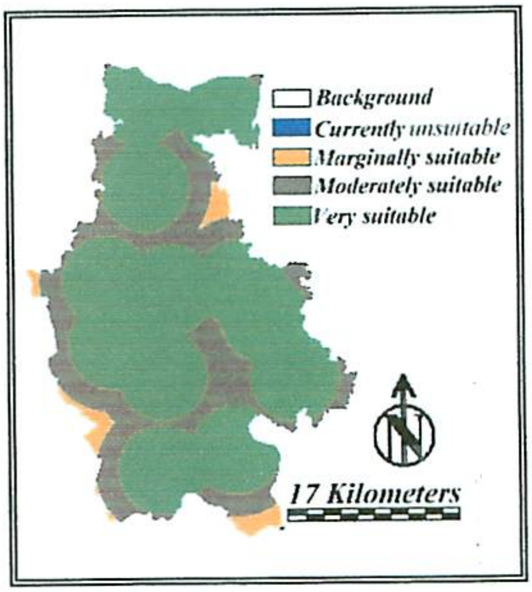


Fig. 33. Support ranges of UFO and DFO in Mymensingh district

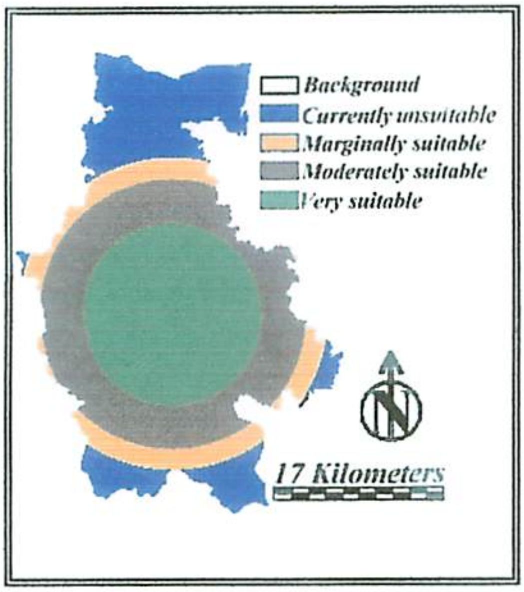


Fig. 34. Support ranges of BAU and BFRI in Mymensingh region

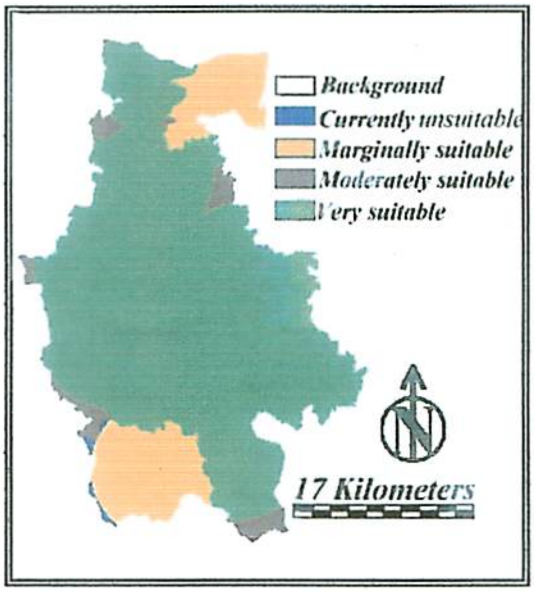


Fig. 35. The support sub-model for sustainable aquaculture development in the Mymensingh region..

4.7 Final result

The final result was obtained from the six sub-models such as water sources, soil quality, infrastructure, market, input and support sub-model through MCE procedure. Fig. 36 and 37 presented the potential sites for development of sustainable aquaculture and suitable land parcels in the study area. Final out come shows that 74% (302,754 hectares) of the Mymensingh district is under moderately suitable category and only 24% (99,415 hectares) area is under very suitable potential sites for sustainable aquaculture development in the area. Marginally suitable category is very few, only 1% (5,359 hectares) and currently unsuitable category is completely absent. The marginally suitable area is situated in the Dhabaura Upazilla due to lack of resources needed for fish culture. The very suitable area is scateredly located all over the district. Although most of the very suitable area is located in Mymensingh sadar, Trisal, Ishargonj, Muktagacha Fulpur and Gaffargaon Upazilla of Mymensingh district due to all or most of the resources for fish culture are available there.

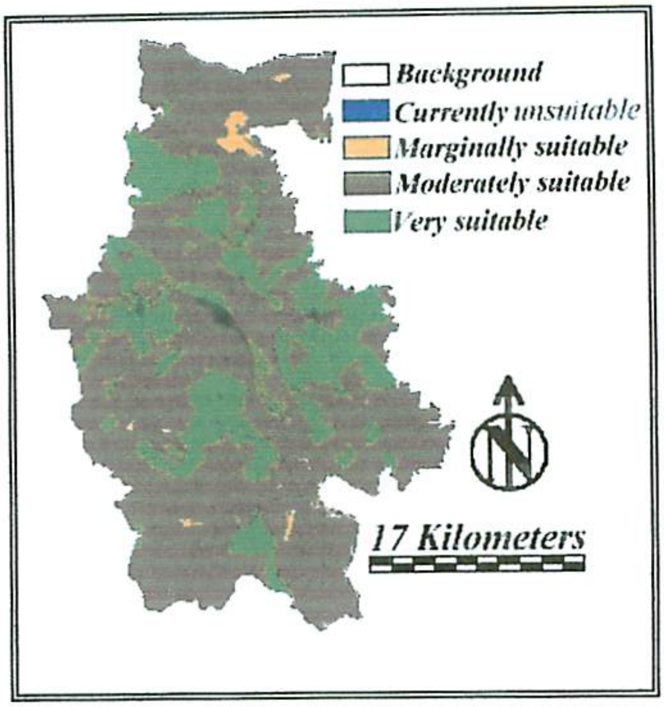


Fig. 36. Potential sites for sustainable aquaculture development in the study area

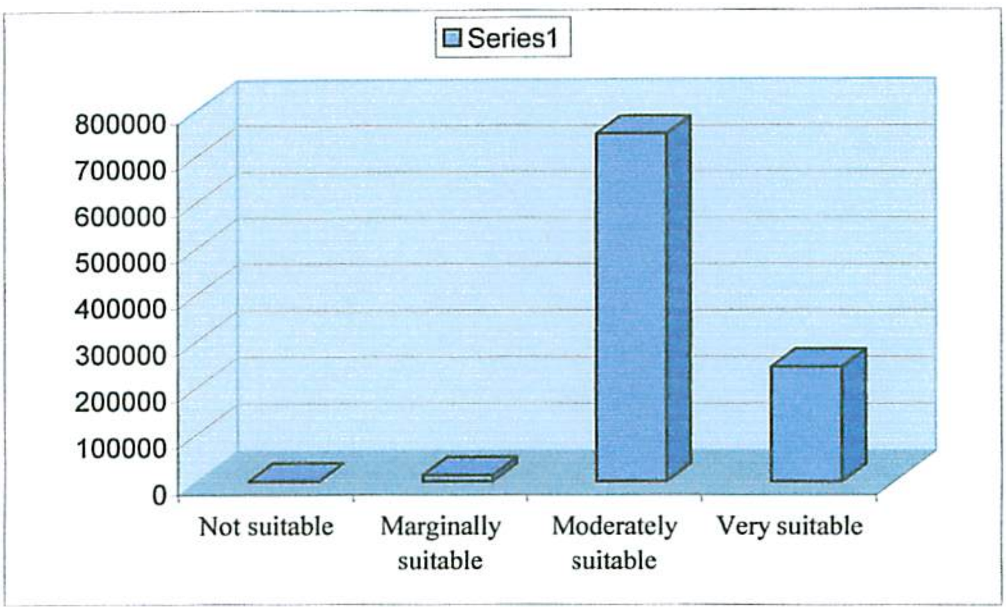


Fig. 37. Summery of the overall GIS modeling result in Mymensingh region.

5. Summary and Conclusion

The major constraints in the development of aquaculture are the conflicts that may arise in terms of land and water uses for various activities (Pollnac, 1992). Aquaculture has been involved in land-use conflict issues in several parts of the tropics, particularly in highly urbanized and overcrowded areas (Beveridge and Philips, 1993). The Bangladesh National Conservation Strategy has identified six important areas of conflicting land use in rural areas. They are (a) agriculture vs. shrimp and capture fisheries; (b) forest land vs. shrimp and capture fisheries; (c) agriculture vs. livestock; (d) agriculture vs. settlements; (e) agriculture vs. brickfields; and (f) agriculture vs. newly accreted char lands (Nishat and Bhuiyan 1995). Moreover, because of the Muslim law every year land is being fragmented, breaking down the available per capita agricultural land into smaller parcels. As a result, more intensified land use, such as intensified mono cropping, and shrimp cultivation and extensive brickfields are degrading long-term soil fertility. On the other hand, unplanned wastes disposal damaging the sustainability in the aquatic sector, such as, destroying breeding and feeding ground and obstructing fish migration (Fig. 38). Cropping on fragile char lands before it has stabilized causes rapid erosion. Flood control and drainage structures have altered land and water use patterns, and led to the decline of fish stocks and production by more than 25% in recent years (Nishat and Bhuiyan 1995).

Fig. 38. Wastes dumped on the bank of Bramhaputra River along with non-degradable polythene which destroying river environment.

Skilled manpower is essential for successful aquaculture operation and usually can be detected in the regions where aquaculture has been established. People with suitable hands-on experience, with some technical background and an education in science, can be found in most areas, and can be trained accordingly. Requirements for well-trained and experienced technical staff are most important in intensive aquaculture projects, whereas those on a small-scale can be supported by extension agencies (Pillay, 1994). In addition, there may be a need for a range of professional and associated services. Obviously the requirement for and availability of each of these will vary from region to region. Technical support is especially difficult to obtain in regions where aquaculture is not established and when problems arise during production. In the present study, there are numbers of NGOs, Upazilla fisheries office; BFRI and BAU provide technical support to the fish farmer. In the area, support sub-model represented that most of the district is under suitable support range for development of sustainable aquaculture. The soil quality of the study area is not suitable for good fish production as in other parts of the country, although more and more land are converting to fish ponds and fish production is increasing day by day due to extension and technical support facilities.

Animal wastes are widely used in small-scale and commercial fish farming systems. The objective of livestock wastes estimation is to predict the amount of manures available for pond fertilization in the region. Due to lack of manure data, number of livestock is used as a surrogate measure to calculate the manure availability.

The total available land in the present study is 407,708 hectares among them only 22% area is under very suitable category for input facilities in Mymensingh district, because rice, wheat, mustard and animal wastes is not sufficient according to the requirement to maintain the sustainable fish production. Moreover, these components have other uses such as rice bran and wheat bran is used for poultry and cattle feed. On the other hand, cow dung is dried and used as fuel for cooking (Fig. 39). The wastes are also used as fertilizer in the agricultural fields. So, it is very difficult to get required amount of components for fish culture purposes. Hence, it is necessary to carry out a survey to find out the amount that is available for use in fish culture. The district has well-established road network and good number of hatcheries and nurseries which supplying fish seed constantly to the farmers. The marketing facilities are also satisfactory. Facilities for aquaculture practices, for that reason is adequate in Mymensingh Sadar. If those facilities can utilize properly, sustainable fish production can be obtained from the potential sites that have been identified through GIS modeling for aquaculture development in the region.

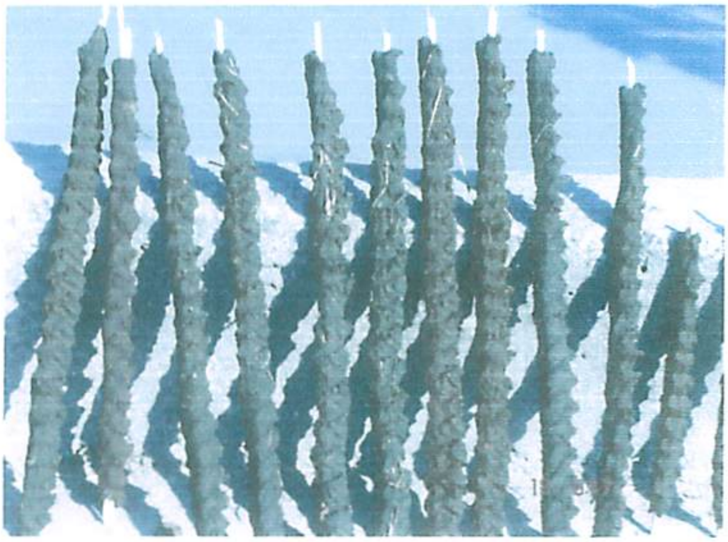


Fig. 39. Cow dung is converted for household fuel

GIS has an excellent future in aquatic sector. The shortage of GIS personnel and the lack of user-friendly interfaces to many existing systems must be considered as another major constraint for application of GIS. However, computer science is continuously evolving and providing a better and cheaper hardware and software, as well as specific GIS application packages that make the work easier and faster. Under the circumstances, it is expected that the number of works in this field will increase. In general, GIS is now becoming more widely adopted technology to a point where many agencies expect to use it in their project planning rather than treating it as an interesting add-on (Ross, 1998). Finally, the GIS process has an important role, particularly where land use patterns are intensive, and where development must be sustainable in terms of sensitive environment issues, as in most part of the Bangladesh. The results of this study are indicative of the modeling power of GIS and could be used to refine the models in future, can also be used in other region or for the whole country.

Acknowledgement

The study carried out with the financial assistance from WorldFish Center. The author is grateful to Dr. Johannes Jansen, Project Leader and Dr. Md. Ferdous Alam, Research Coordinator of DSAP, for their kind support. The author is also grateful to DFO, DAO, all UFO of Mymensingh, WARPO, BARC, E-GIS, and the farmers who help with the information to complete the study.

6. REFERENCES

ADAB, 1998-1999. Directory of NGOs in Bangladesh: Association of Development Agencies in Bangladesh. Dhaka, Bangladesh.

Aguilar, M. J. and Ross, L. G., 1995. Geographical information system (GIS) environmental models for aquaculture development in Sinaloa State, Mexico. *Aqua. Int.*, 3: 103-115.

Aguilar, M. J. and S. S. Nath, 1998. *A strategic reassessment of fish farming potential in Africa*. Food and Agriculture Organisation , Rome, Italy.

Aronoff, S., 1989. *Principles of Geographical Information Systems: A Management Perspective*. Ottawa: WDL Publications.

Boyd, C. E., 1990. *Water quality in ponds for aquaculture*. Auburn University, Alabama Agricultural Experiment Station, Alabama, USA.

Chaua, T. E.,1986. An over view of the fisheries and aquaculture industries in Asia In: J. L. Maclean, L. B. Dizon and L. V. Hosillos (eds). The First Asian Fisheries Forum. *Asian Fish. Soci.*, Manila Philipines pp. 1-8.

Clarke, K., 2001. *Getting Stated with Geographic Information Systems*, 3rd ed., Upper Saddle River, NJ: Prentice Hall.

Coche, A. G. and T. Laughlin, 1985. *Simple methods for aquaculture: Soil and freshwater fish culture*. Food and Agricultural Organisation, Training Series 6, Rome, Italy.

DeMers. M. N., 2000. *Fundamentals of Geographic Information Systems*, 2nd ed., New York: John Wiley and Sons.

Eastman, J. R., 1995. *IDRISI for Windows User's Manual*. First edn, Clark University Graduate School of Geography, Worcester, MA, USA, 120.

Eastman, J. R., 1997. *IDRISI for Windows User's guide* : Clark labs for cartographic technology and geographic analysis. Clark University Graduate School of Geography, Worcester, MA, USA, 290.

Eastman, J. R., 1993. *IDRISI version 4.1 Update Manual*. Clark University Graduate School of Geography, Worcester, MA, USA, 120pp.

El-Gayar, O. F., 1997. The use of information technology in aquaculture management. *Aqua. Ecol. and Mant.*, 1(1): 109-128.
FAO, 1997. The State of World Fisheries and Aquaculture, Food and Agriculture Organizations of the United Nations, 125p.

FAO, 1999. Geographic Information Systems in Sustainable Development (Web Page), Available at http://www.fao.org/sd/Eldirect/GIS/ElgisO00.htm.

Heywood, D. I., J. Oliver, and S. Tomlinson, 1995. Building an exploratory multi-criteria modeling environment for spatial decision support. In: *Innovations in GIS*. Fisher. P. (ed). Taylor and Francis, London, 2: 127-136.
Jarayabhand, S., 1997. Management of Coastal Aquaculture in Thailand. A ph. D thesis submitted to the Adelaide University, Australia.

Kapetsky, J. M., L. McGregor and H. E. Nanne, 1987. A geographical information system and satellite remote sensing to plan for aquaculture study in Costa Rica: a FAO-UNDP/GRID co-operative study in Costa-Rica. FAO Fish Tech. Pap. 287: 51.

Kapetsky, J. M. and S. S. Nath, 1997. A strategic assessment of the potential for freshwater fish farming in Latin America: COPESCAL TECHNICAL PAPER 27, Food And Agriculture Organisation, Rome, Italy.

Kapetsky, J. M., 1994. A strategic assessment of warm water fish farming potential in Africa: CIFA Tech. Pap. No. 27, FAO, Rome, Italy. 67p.

Mazid, M. A., 2002. Develovement of fisheries in bangladesh: Plans and strategies for income genertion and poverty alleviation.176p.

Meaden, G. J. and J. M. Kapetsky, 1991. Geographical Information Systems and remote sensing in inland fisheries and aquaculture. FAO Fish Tech. Pap.no.318. FAO, Rome, Italy. 262p.

Muir, J. F., 1995. Aquaculture development trends: Perspectives for food security. In: Proceedings on International conference on sustainable contribution of fisheries to food security, Kyoto, Japan. Nugent, C. G. (ed.) KC/FI/95/Tech/4. FAO, Rome, Italy.

Muir, J. F. and Kapetsky, J. M., 1988. Site selection decisions and project cost: The case of brackish water pond systems. An abstruct. In: *Aquaculture engineering: Technologies for the future*, Symposium series No.111. The Institute of Chemical Engineers, EFCE publication No. 383, 45-63

Muir, J. F. and M. C. M. Beveridge, 1987. Water resources and aquaculture development. *Archives of Hydrobiology*, 28 321-324.

Patricia, W., 1999. Keynote: Integrating our World; Rivers of discord, rivers of peace. *In*: *GeoSolutions: Integrating Our World*. Vancouver, B.C., Canada, Adams Media, Vol.13.

Phillips, M. J., M. C. M. Beveridge and Clarke, 1991. Impact of aquaculture on water resources. In: *Advances in World Aquaculture*. Brune, D. E. and J. R. Tamasso (eds). 3 pp. 568-591.

Rahman, M. S. 1992. Water Quality Management in Aquaculture. BRAC prokashana, Bangladesh Rural Advancement Committee, Dhaka, Bangladesh, 84p.

Ravenholt, A., 1982. Malnutrition in the Philippines. UFSI Rep. Southeast Asia Ser.20:73-84.

Saaty, T. L., 1977. A scaling method for priorities in hierarchical structure. *J. Math. and Phys.*, 15: 234-281.

Salam, M. A. and L. G. Ross, 1999. GIS modeling for aquaculture in South-western Bangladesh: Comparative production scenarios for brackish and freshwater shrimp and fish. *In: GeoSolutions: Integrating Our World*. Vancouver, B.C., Canada, Adams Media, Vol.13: 141-145