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Methods and Techniques for Promoting a Multidisciplinary Environmental Research Project using GIS

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This study demonstrates collaborative methodologies and techniques using GIS (Geographic Information System) for multidisciplinary environmental research by self-evaluating trial-and-error practices in a multidisciplinary research and education program at Yokohama National University (YNU). It describes changes of the activation level of GIS use throughout the overall and individual research projects in the program. This study analyzes the trigger factors by conducting interviews of participating researchers. As a conclusion, it proposes new ideas to promote a multidisciplinary environmental research project that makes use of GIS. Experiences and lessons learned from this program are useful for designing and implementing new multidisciplinary environmental projects beyond YNU and Japan.

Keywords: Multidisciplinary, Collaboration, Ecosystem management, Database and system building, Capacity building, Coordination.

1. Introduction

Complicated environmental problem solving requires integrated and comprehensive research approaches and collaboration among various researchers. Geographic Information Systems (GIS) serves as a means to align research approaches and facilitate collaboration, and will become an important technology to solve environmental problems. Many GIS processes such as data capture, storage, analysis, visualization, and web publishing can facilitate advanced and effective spatial information management. Multidisciplinary environmental management projects using GIS will likely expand in number and scope because difficult environmental issues require new approaches that take into account multiple viewpoints.

There are numerous examples of GIS technologies being used for conducting environmental management research.[1−3] In addition, many non-technological issues related to conducting multidisciplinary environmental research must be considered to realize the research potential of multidisciplinary approaches. Research into collaborative methodologies and techniques among various stakeholders has been implemented in several research fields such as those of community planning,[4] town workshops, and disaster mitigation processes.[5] Tanaka *et al* [6] proposed a methodology of an environmental town design workshop using GIS. Nonetheless, problems with implementation in research still remain. Resolutions of technical issues and research into techniques for GIS utilization are necessary to meet the expectations of GIS utilization for environmental management projects.

This study is intended to provide collaborative methodologies and techniques using GIS for multidisciplinary environmental research by self-evaluating trial-and-error practices at Yokohama National University (YNU)'s program on Environmental Risk Management for Bio/Eco-systems. This paper describes the changes of activation level of GIS use overall, and those in individual research projects in the program. Furthermore, it analyzes a wide variety of factors through interviews of participating researchers. Experiences and lessons learned from the program will be useful for designing new multidisciplinary environmental projects in other locations. This study, then, is a first step toward accumulating general know-how of GIS utilization in a multidisciplinary project environment.

2. Program Outline and GIS Utilization

2.1. *Program outline*

Japan's Ministry of Education, Culture, Sports, Science, and Technology (MEXT) selected YNU as a 21st Century Center of Excellence (COE) Program for a 5-year program during 2002–2007. This COE program was designed to collect and evaluate environmental risk information with a primary focus on East Asia, including Japan. In all, 18 professors and 14 post-doctoral fellows from the fields of biology, ecology, botanical sciences, soil science, geological science, agricultural sciences, oceanography, environmental toxicology, and social sciences participated in this program.

To guide their efforts, the group proposed a set of guidelines for assessing community-level ecological risk management. The guidelines distinguished four tasks: first, getting the relevant stake holders involved; second, attaining a basic scientific understanding of the problem; third, reaching agreement on a risk management plan; and finally, implementing the plan, which may, depending on monitoring results, require adjusting targets and methods.[7] The project established ecological environmental risk assessment methods and developed concepts and ideas for risk management[8,9] based on the concept of the Millennium Ecosystem Assessment.[10] The main study areas inside Japan, such as Mts. Tanzawa, Kanagawa Prefecture and Yakushima Island, are shown in Figure 1.

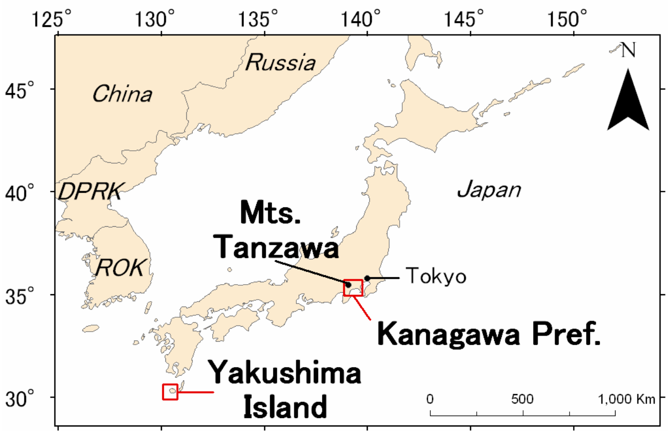

Figure 1 Main study areas in Japan.

2.2. *Organization and roles of GIS*

Three research groups organized the program: the first group studied environmental risks for terrestrial systems of vegetation and forest ecosystems, and soil organisms and soil ecosystems. The second group investigated environmental risks for aquatic systems and studied the adverse effects of toxic chemicals on the ecosystems. The third group stored the collected environmental risk information (the results of which were later analyzed by the first and second groups to produce models), processed the results into a GIS database and uploaded them on the web. The third group also played supervisory roles and gave thought on how to form an improved education system. From the beginning of the program, researchers considered GIS an important tool for research and education, developing a core information system, promoting individual and multidisciplinary research, and publishing information on the web.

2.3. *GIS utilization and results*

Figure 2 outlines the responsibility of GIS in the program. In fact, the first and second groups used GIS both as a central data storage system and for social statistical data related to human activities. Weather and geographic features were also stored into the common GIS data format, called the geodatabase.[11] A spatial data sharing system was developed to promote the use of GIS databases among participating researchers.[12] In addition, a water flow network geodatabase was developed in the pilot area, allowing researchers to trace water movement from the mountains, through population settlements, and into the ocean. The database includes artificial pipe systems to connect the results obtained by the first group that researched the forested mountains with those of the second group that studied middle and downstream areas (Figure 3).

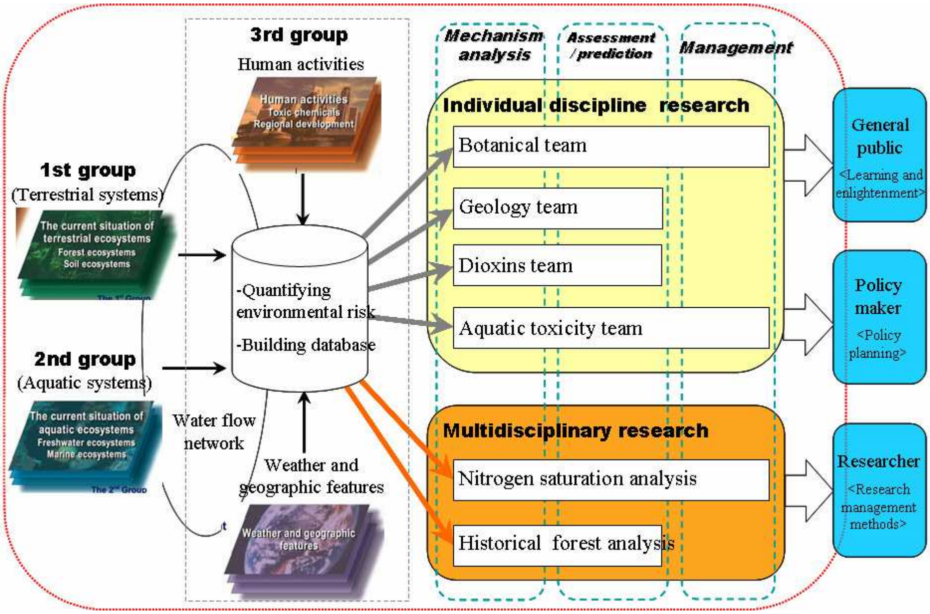

Figure 2 Roles of GIS in YNU-COE program.

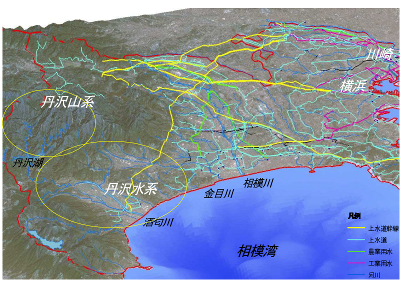

Figure 3 Waterworks network database in Kanagawa Pref.[13]

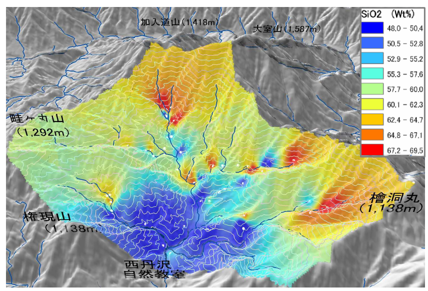

Figure 4 Concentration distribution of geological element (SiO_2).[14]

As a result of our trial to establish procedures and systems to integrate spatial data for researchers from a wide range of specialties, individual participant researchers conducted several environmental management research using GIS in both terrestrial and aquatic systems, especially during the last half of the program. Program officers identified the Tanzawa Mountains and its basin as a common research field; GIS related works were conducted intensively in this area (Figure 1). The geological team in the first group researched the distribution of tonalitic soil structure and geochemistry (Figure 4) and analyzed historical slope failure in the mountain areas.[15] The botanical team studied the topographical distribution of

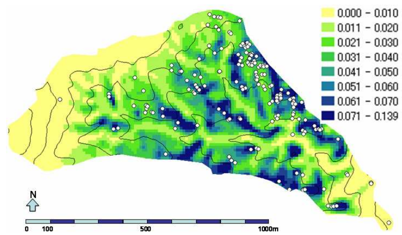

Figure 5 Distribution probability for Abies firma trees larger than 50 cm in basal diameter in a watershed on Mts. Tanzawa.[16]

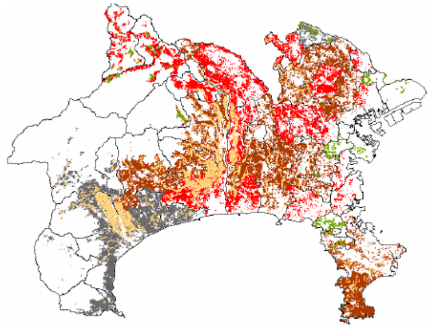

Figure 6 Estimation of pollutants discharged load into water in Kanagawa Pref.[18]

forest trees such as Fagus crenata and Abies firma in a watershed on the actively denuded mountains (Figure 5). Researchers also conducted GIS-based research in Yakushima Island. The botanical team assessed the risk of economic damage to crops caused by Japanese macaques.[17] The second group studied middle and downstream areas and estimated and mapped pollutant discharge loads into water areas (Figure 6). The group also analyzed the behavior of zinc in urban aquatic environments.[19]

By improving the individual laboratories' opportunities for GIS utilization, the project both increased the number of overlaid GIS layers and promoted constructive dialogue. In doing so, project researchers overcame many of the obstacles that inhibit multidisciplinary research. This led to collaboration among researchers of various disciplines in a nitrogen saturation survey and analysis project.[20,21] Researchers used both satellite images and archived field collection vegetation data to create quantitative data that illustrates the historical trends and current status of the Tanzawa Mountains.[22]

3. Investigating Triggered Factors for Motivating the use of GIS for Multidisciplinary Environmental Research

3.1. *Temporal qualitative evaluation of GIS activation level in the program*

This section, investigates how researchers changed the ways in which they used GIS over the 5-year period, and considers the factors that led to these changes. First, program participants defined the qualitative degree of GIS utilization for research and overall multidisciplinary collaboration as the activation level of GIS-related studies and collaborative activities. It included: the interest in using GIS for research activities by participating researchers; the frequency of GIS-related discussion and the collaborative situation toward multidisciplinary research;

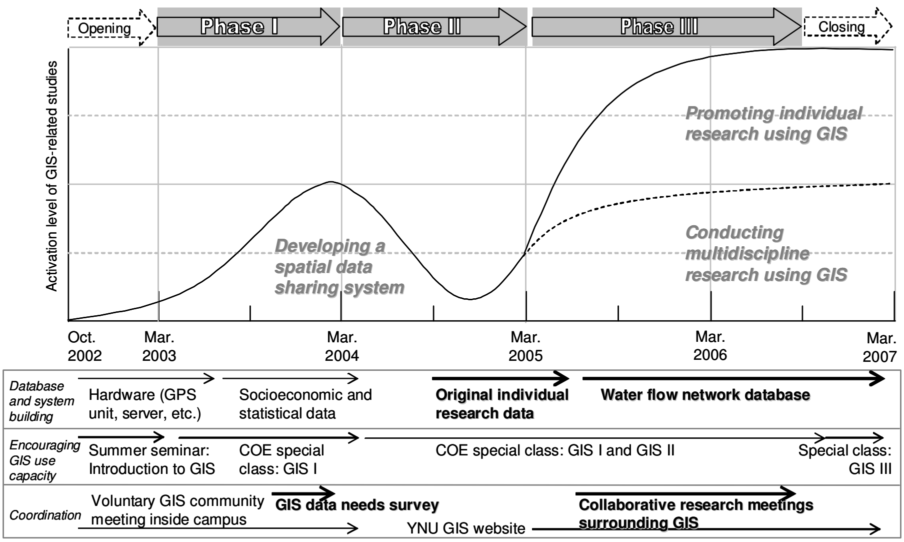

Figure 7 Temporal self-evaluation of activation level of GIS related work.

contributions for updating, expanding and using a central GIS database; and participation in GIS-related activities such as GIS classes and seminars. Authors used interviews with participating researchers from the start to the end of the program to describe changes of qualitative activation levels over time. These changes are portrayed in Figure 7. The activation level of GIS-related studies and collaborative activities in the program were divided into five parts and titled from our self-evaluation. Regarding the entire evaluation, although GIS utilization slumped in the program's middle stage, the activation level increased rapidly in the last half of the program and produced many research results. The following are summaries of respective phases, minus the opening and closing periods, showing related events and trials as triggered actions and continuous supporting activities for raising the activation level.

Phase I (Building up unspecified expectations of GIS utilization)

Participating researchers' expectations for GIS utilization increased gradually from the start of the program, as the authors proposed the use of GIS in the program, and demonstrated both functions and examples of GIS utilization for each study field.

Phase II (Slump in GIS activity)

The GIS activity level decreased drastically, however, after launching a spatial data sharing system at the beginning of the third fiscal year. The low level of GIS users in this stage served as the main cause of researcher's failure to use the system well. Many had difficulties visualizing GIS utilization for their own research and the entire project. As a matter of fact, only socioeconomic and statistical data were prepared in the database.[12] Authors conducted a GIS data needs survey of all participating researchers in the second year to elucidate what kind of data they were able to provide and what kind of GIS dataset layers would be useful to increase the level of GIS use in all projects. We had no other choice but to develop a data sharing system with socioeconomic and statistical data that were easy to obtain because the response rate of the questionnaire from participating members was low.

The responses to the interviews showed that participating researchers appreciated the various data sets—such as social statistical data and geological data—that were prepared in preparation for their research. In addition, the research groups require setting up guidelines or rules for data sharing and provision, even internally to the program. Without such requirements, researchers hesitate to store their data in integrated databases, and hence impede data sharing. Reviewing this process in light of participants' opinions, developing an information sharing system might better have been postponed to the last half of the program, after the assessment of participant needs and the GIS level of use.

Phase III (Full progress and deepened GIS activity)

In this phase, understanding and use of GIS increased like a chain reaction. The conducting of individual research actually triggered more extensive multidisciplinary research. Many laboratories conducted their own research using the GIS database and attempted to integrate data with other spatial data in a natural manner. Almost all GIS-related results described in section 2.3 were produced during this period.

Researchers opened the gateway for multidisciplinary environmental research projects using GIS through this process. Figure 7 shows that the activation level of using GIS for multidisciplinary and individual use of GIS actually fluctuated wildly. The highly increased activation level was mainly attributable to the following triggers: our providing support to help convert participants' research result data into a GIS platform, and careful follow up to make sure researchers were making full use of GIS during Phase II; our decision to provide a comprehensive research theme in Phase II; attempts to create research results and connect the databases during Phase II; and the continuous GIS supporting activities from the starting point of the program. Details of each contributing element are described in the following section.

3.2. Promoting individual GIS activities as trigger factors for multidisciplinary research

3.2.1. Supporting conversion of own-captured individual research data into integrated GIS databases and preparing multidisciplinary research themes

During the slump period, the authors visited the participating laboratories several times. We helped convert their original research results' data into a common GIS data format. In doing so, we sought to reinforce the database and promote GIS utilization for their research topics. Through discussions with researchers, we gradually clarified the existence of important data sources in each laboratory: some were the results of current field surveys and analysis; some were archived research resources that had been stored in the laboratory in paper format. We continued supporting the GIS data creation by providing GIS advice, intensively, for half a year.

Through such GIS data creation support, many researchers became able to overlay their own data onto a common GIS platform. They were then able to discuss the spatial relationships among data layers. This is a basic concept of GIS utilization for enhancing collaborative work. We were unable, however, to enhance such collaboration without taking the time to give participant researchers, step by step, hands-on experience using GIS.

Periodically, we had opportunities for discussing the interrelationships among layers, especially in forested mountain areas such as geological features, geology, soil, vegetation, water chemistry, slope failure, and satellite images. We also explored the possibility of forest ecosystem mechanism analyses from widely various viewpoints.

Using information from those interviews, the difficulties of conducting multidisciplinary research became clear, owing to the difference of disciplines. However, bringing their own captured GIS dataset into a common discussion platform helped bridge disciplinary gaps. It encouraged discussion of data sets among various researchers of different disciplines. Furthermore, a soil researcher valued GIS for its visualization and bird's view functions because the differences of ecological systems can be viewed using a beautiful designed map (such as a geological map) that converts various research field data in a common GIS platform. Soil researchers gained particular insight through explanations of the differences of geological systems, which they often visit. By creating GIS data and overlaying it upon other data layers, unclear situations were clarified using GIS overlay and visualization functions.

Further, a leader of the first group also proposed collaborative research targeting nitrogen saturation in forested mountains as a simple research framework for promoting collaboration among forested mountain researchers. Current research attention for nitrogen management is high in science fields.[23,24] Designing an attractive research topic with a high scientific profile is very important for motivating scientific researchers' participation. Additionally, collaboration among various research fields—from upstream to middle and downstream—is necessary to explain, comprehensively, the behavior of nitrogen in the basin. In fact, GIS is necessary for organizing and integrating the environmental situation such as land cover, terrain, water flow, and precipitation in the study area. Setting up clear research targets will help researchers prepare a suitable database with proper spatial scales. These two points show how GIS in forested mountain areas can be used to foster multidisciplinary research.

3.2.2. *Creating a water flow database for use among researchers*

Through discussions with researchers over several years, we rediscovered water as an important component of many environmental topics because it is a common vehicle for transferring chemical substances from mountains, through population settlements, and to the ocean. This process circulates in a watershed basin. Therefore, we used the basic concept that these databases would not only integrate spatial barriers that divide research subjects according to various scales in space, but also vertical barriers, which divide the research according to the subject matter.

We used both ESRI ArcGIS and Arc Hydro technologies[25] to build these databases by digitizing paper maps of water systems, storm and sanitary sewage systems, and industrial and agricultural irrigation canals from individual departments of the city government. Attribute data related to manmade water systems include the flow direction, flow amount and quality, junction types. Those data were combined with data related to the natural flow of surface water in each watershed, as calculated using a Digital Elevation Model. Water flow geodatabases were built for both the main water network in Kanagawa Prefecture and for the local water network in Isehara City, Japan (Fig. 1). Consequently, these databases not only to supported the multidisciplinary approach to research but also promoted individual discipline research analysis and surveys in second research group's middle and downstream research (Fig. 7) as well as the first group's upstream research.

To share data, some datasets we created were disseminated on the web—both the water flow database and integrated GIS database described at 3.2.1.[12] However, copyright and ownership restrictions at times inhibited data sharing. While we created some datasets, sometimes they were based on paper maps owned by local governments. In addition, intellectual property rights by researchers became a major issue. Many researchers hesitated to share data unless they received a guarantee that their work would be acknowledged in the final product. Some dataset creators demanded co-authorship, and others requested to be included in the acknowledgement section of any papers that make use of the dataset.

3.2.3. *Supporting activities for building research and educational infrastructure*

The following two were not direct factors for improving the use of GIS in the project but are nonetheless important factors for considering the growth of the activation level in phase III. No growth took place without following basic supporting activities:

(i) **GIS education for encouraging students' capacity of researching a field** The educational concept of the program sought to educate researchers who can think globally, act practically, and develop study results of environmental risk management for Bio/Eco-systems. We regarded GIS as an important tool for students and researchers for achieving the educational purposes of this program. Therefore, we launched new classes on GIS as COE special classes from the second fiscal year. The GIS class concept did not merely involve software training. It also encouraged students' capacity to imagine how GIS might be useful for research in their own field. Therefore, the classes were designed so that students could implement independently a series of GIS functions to support their own research topics — from collecting field data to designing research flow, processing spatial analysis, and visualizing and presenting results after taking the classes (Figure 8). Around 40 students from various laboratories took the class each year. These students became important human resources for supporting GIS activities in both individual research laboratories and the program's larger overall projects.

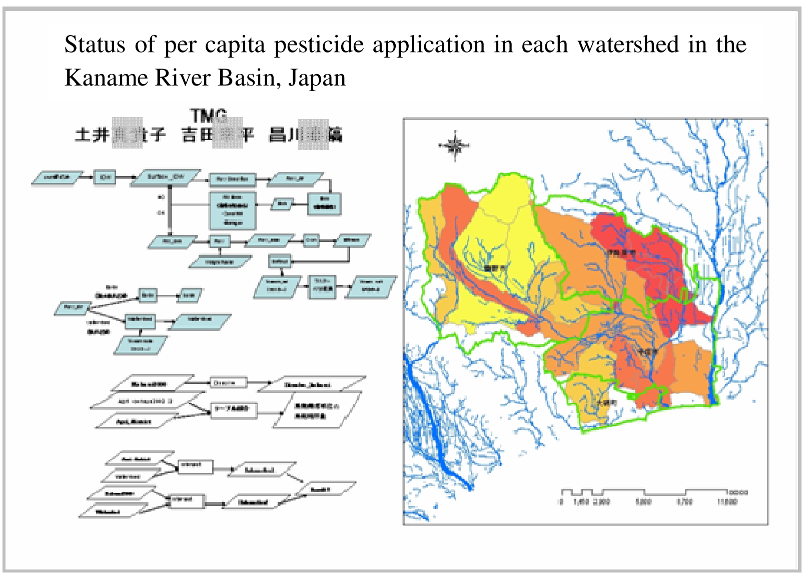

Figure 8 Example of student's result of creating analysis flowchart in a GIS exercise class.

(ii) **GIS coordinator** Coordinating GIS solutions and the scientific demand by participating researchers is critical for conducting multidisciplinary environmental research using GIS. The authors acted as GIS coordinators in the program and struggled to promote collaborative research among various research fields using GIS for the entire 5 years of the program. However, acting as a GIS coordinator in this kind of program was difficult for most researchers because such activities were not evaluated as an academic achievement, even though mutual trust among participants in the program was obtained. But owing to the critical role of GIS coordination, the creation of a position of GIS Coordinator ought to be seen as of the highest priority.

The GIS Coordinator is one of the few administrators able to create opportunities for common discussion in a project team. Such a coordinator must have knowledge of GIS solutions and techniques — in addition to a cooperative personality — to respond and propose GIS solutions based on participants' needs. These tasks were difficult to evaluate as research results, although they play a critical role in advancing multidisciplinary projects. In addition, allowing GIS utilization to take root among program members was important for forming a kind of center of excellence, instead of merely responding to temporal GIS support. Therefore, we tried to support GIS data creation by taking participating laboratory members by the hand and teaching them step-by-step, describing the GIS data creation process, and sharing it on the YNU GIS community website (closed Mar. 2007). It was an important but a long and strenuous task.

4. Conclusion

This paper described changes of the GIS activation level throughout the overall and individual research projects in the program. This study analyzed the trigger factors by conducting interviews of participating researchers. Experiences and lessons learned from this program are expected to be useful for designing and implementing new multidisciplinary environmental projects in other locations.

This project sought to conduct collaborative multidisciplinary research through the use of GIS. We learned that it is not easy to introduce and convince participating researchers to use GIS, especially in the absence of a common and clear objective shared by the research group. Looking forward, there are a number of other problems that might impede collaborative work. For instance, most members might not know each other or have strong working relationships before the project begins. Alternatively, participants might not be familiar with GIS. In addition, the GIS Coordinator or supporting staff might not understand the details of the individual participants' disciplines. Therefore, we recommend taking plenty of time to interact with each participant and to teach and promote the use of GIS

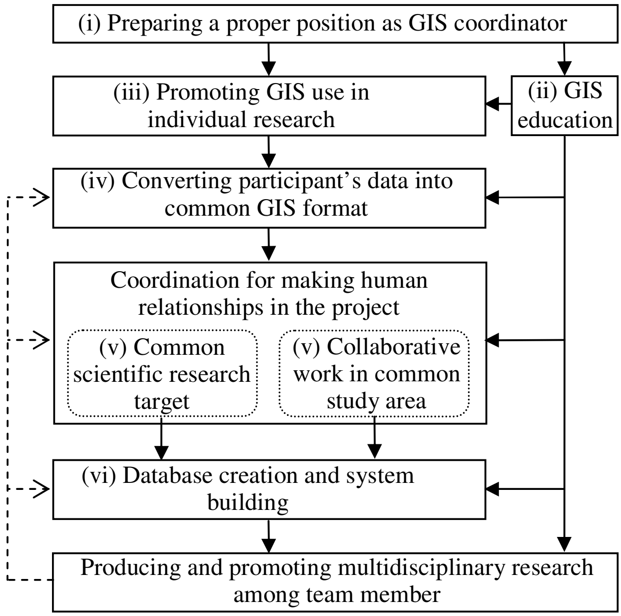

Figure 9 Example of student's result of creating analysis flowchart in a GIS exercise class.

as initial steps toward multidisciplinary GIS work. We propose the following as important factors for conducting a multidisciplinary environmental research project using GIS (Figure 9).

(i) **Preparing a proper position of GIS coordinator from the project's get-go.** (Preparation stage)

(ii) **Starting GIS education from an earlier stage**: This will build a strong infrastructure and serve an important role for further development of multidisciplinary research in the project's later stages. We recognize that it may take a long time to get used to GIS. In other words, it might be difficult to achieve concrete results in a short time. Encouraging GIS use is essential to promote GIS collaboration among various researchers. It would allow participants to build connections across disciplines through preparation of group work in classes.

(iii) **Promoting GIS use in the project by supporting individual research (Initial stage)**: Continuous dialogue with each participating researcher is of critical importance for a successful project, but it is especially important at the project's early stage. It will help build human connections for later collaboration and deepen the understanding of research objectives and existing data by participants. In other words, it would help each researcher to see how their individual project fits in the greater whole. Therefore, recognizing that the acceptance of GIS by participants can take a long time is important; otherwise it might make both the coordinator and participants feel uncomfortable.

It is important to support and promote the use of GIS for conducting individual research projects among each participant who either just started, or have a strong interest, in using GIS. For members who do not know much about GIS, it would be helpful to provide information about GIS utilization.

(iv) **Converting participants' research data into common GIS data format (Initial stage)**: Transferring survey data obtained by each participant into common GIS format would support the start of collaborative work in the common study area. Of course, creating GIS data in different places is also important for future collaboration, if sufficient data are available in a common place. Having one's own GIS data, even outside the common field, would give additional motivation for collaborative studies using GIS.

Giving all possible assistance for participants' GIS data creation is critical for early stages of the project. Providing such assistance is hard work for both the GIS coordinator and supporters because it takes a long time to teach the process of data creation to participating members. Nevertheless, it is a good opportunity to understand how the individual data from various disciplines relates to the broader project, and it would help participants build stronger working relationships.

(v) **Strengthening human relationships through GIS collaboration (Initial to practical stage):** Making small connections among researchers in a step-by-step manner would be helpful if the project has relevant topics for. In such cases, starting a couple of small joint projects among various disciplines will likely be fruitful. Over time, common themes and problems necessitating linkages among research groups or topics might emerge through repeated discussions among members. It might engender new scientific topics which connect the entire project.

After seeking advice and collaboration from leading researchers in the program, it would be effective to establish common research topics across various disciplines. Such a strategy would help establish common research targets, including scientifically hot topics, and would support active discussion across research disciplines.

Creating a mechanism for sharing GIS data creation know-how would also be effective for accumulating GIS knowledge.

(vi) **Database creation and system building (Practical to final stage):** We recommend designing integrated databases for collaborative projects and expanding databases with minimum datasets to promote the project target during the last half of the project. Designing and developing relationships that allow connections among individual layers in the database might help to promote collaborative research.

Acknowledgments

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