© 2015 IJSRSET | Volume 1 | Issue 3 | Print ISSN : 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

A Review of Applied GIS Based in Sustainable Water Resources Management in Malacca River
Case Study: An Observation Perspective

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ABSTRACT

Water resources have become an issue in supplying freshwater for human to carry out daily activities. The reasons for this problem water pollution occurring in rivers. Among the methods to overcome this problem is the adoption of the concept of sustainability in water resources management in Malacca River. Practicing this concept will require a technology to help in planning as a whole, namely Geographical Information System or GIS. GIS is a tool widely used in determining the quality and quantity of water resources, especially at the river basin scale, to manage water resources. The site selection for observation in this review paper is Malacca River, which have a wide river basin and suitable for study. As a result, GIS has the ability to combine various data and provide an answer for decision making in sustainable water resources management in Malacca River, such as physical perspective data (elevation and slope boundary, landuse data, meteorological data, hydrological data, etc.) and human perspective data (demographic and population data, stakeholders and businesses data, etc.). GIS helps users to develop a new model (for example water quality model) which become a main point in saving and protecting the environment and the human society.

Keywords: Water pollution, sustainability, management, GIS, protecting.

I. INTRODUCTION

Sustainability concept is a term widely used in the daily life. There are various definitions used for sustainability, which may be defined as a system with the capacity that should maintain output equally with the historical average [8] and maximize economic development benefits with maintaining service and natural resource quality [10]; and the external events like climatic change and natural disasters become a factor to cause change and modification of natural inputs and outputs [3]. However, the general definition always referred to and used for sustainable development is that any demand for current generations in development should not be compromising the ability for needs and aspirations of future generations [13]; and that this development will improve human life quality without interfering with an ecosystem [6]. However, these definitions are still consider as unclear, simplistic, and inconsistent to applied in all fields, so there are some experts that continue to criticize the definition.

According to ASCE [6], the sustainable concept can be applied to water resources, which can be defined as the sustainable water resources system that designed and managed to fulfill the objective in contribution towards the society, not only for today but also for the future, meanwhile maintaining the ecological, environmental, and hydrological integrity. In other words, sustainable water resources not only involve with ethical and moral value, but also implicate with the renewability, resilience, and recoverability. According to Hussain [5], the development of economic growth should react together with preservation of natural wealth like flora and fauna, as well as environmental cleanliness, so that future generations can have option and right to the environment; meanwhile renewability indicate a source can be replaced, resilience signifies ability to withstand stress for a long-term or any damage that unable to be restored, and recoverability is defined as a concept that concentrates on the rate or frequency of impact to have a possibility for recovery [2]. So, in order to facilitate the assessment towards sustainability, Xu *et al.* [11] had designed an index known as the sustainability index (SI), and this formula can be written as below.

$SI = (S – D) / S$, where $S > D$;
$SI = 0$, where $S \leq D$

*SI is Sustainability Index
*D is demand
*S is supply.

Per the Xu *et al.* [11] research study, an *SI* value bigger than 0.2 means there are no stress on water supply (where demand ≤ 80% of potential water supply), and when *SI* value is smaller than 0.2 means the water supply conditions is affected (where demand > 80% of potential water supply). For example, when *SI* = 0, the result show that water demand is higher than available water supply, and this is unsustainable for water resources. So, this conditions show that it is important to use the sustainability concept together with water resources management in society.

In effort to manage water resources, it is important to recognize the main point of the source to conduct management activities, for example, a river. A river will flow in different directions, moving from the river upstream (high area) to the river downstream (lower area). Usually, these small rivers will join with another small river at one point to form a main river, which contribute large benefits in the water supply system. This could happen when there are various small rivers joining together with main river will forming a huge river basin or watershed; and this will result to the concept of integrated water management (IWM). Naturally, there are hundreds of river basins that exist in a particular area, and this should result to the exceeding of benefits like water supply. So, the IWM will be applied to sustain the water supply and maintain the ability to forecast for the future generation. This IWM model will involve several functions, such as the need for water, the policy to meet the needs, and the management to implement the policy (figure 1). Generally, this model is believed to be the most helpful in solutions towards water resources problems by combining all essential component models into an optimization scheme. The model will combine all of interactive forces or influences forces. Therefore, the model assists the decision-making process and keeps policy within the intersection of social goals of management policy and legal constraints.

Water elements comprises of physical, chemical and biological aspects of water quality and quantity that become the first dimension to be involved in carrying out almost every activity. The water elements will have internal interaction and also be effect from natural disruption (example climate change, uncertainty climate, extreme climate, etc.) as well as external disruption (such as increasing demographic, economic development, transportation development, etc.) to them, as this will cause negative reaction on water system and result in the development of the IWM model. As shown in figure 1, water uses for particular activities will impact the interaction within the water system. These activities include agriculture, water supply, energy generation, industry, fish production, recreation, transportation, and are together considered as the second dimension. At the same time, the usage towards the water is compulsory to have a balance with the demand for different uses, and this can be achieved by having a well-defined management policy, which is considered the third dimension. The suggestion for management policy to be established should concern certain criteria such as economic efficiency, environmental impact, ecological and health consideration, socio-cultural and so on, must be practical, implementable, and acceptable to society at large. The results after implementation policy must achieve the interactive social goals as equity, efficiency, environment quality, and others.

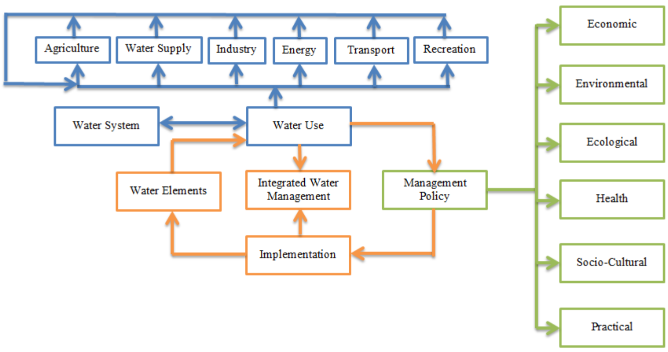

Figure 1: The function of integrated water management. Retrieved from the Book of Water Resources Systems Planning and Management, written by Jain and Singh (2003).

The *Dublin Principles*, a set of principles for good water resources management originally formulated from the United Nations Water Conference in Mar del Plata in 1977 and the International Conference on Water and the Environment in Dublin, and the Earth Summit in Rio de Janeiro in 1992, can be referred to as follows:

1. Ecological Principle –water should be protected as primary resource within river basins, with particular attention to the ecosystem.
2. Institutional Principle – water management should involve the government, civil society, and private sector, and the principle will be automatically respected. In addition, women's roles are also important to get involved in water management.
3. Instrument Principle – water should be recognized as an economic good, and the user, polluter, and other business instruments should pay for every greater use of a water resource.

At this moment, sustainable concept and management principles towards water resources are believed to have a higher percentage in terms of keeping the quality in quantity for future generation. Therefore, this review study has been carried out to determine how a GIS (Geographical Information System) based on a computer technology system to help in sustaining and managing the water resources in the Malacca River.

II. METHODS AND MATERIAL

GIS is a tool widely used in determining the quality and quantity of water resources, especially at a river basin scale, to manage water resources. Before an analysis in GIS, it is important to know what are the data needs to analyze in providing information. There are two categories to be considered, namely physical perspective data (such as elevation and slope boundary, landuse data, meteorological data, hydrological data, etc.) and human perspective data (such as demographic and population data, stakeholders and businesses data, etc.). Both data are essential in determining the effectiveness of river water resources management. However, it is required to understand the concept of water management model in a river (especially in different landuse like residential area, industrial area, irrigation area, etc.) to help in gathering the data. The water management model can be explained per the following figure:

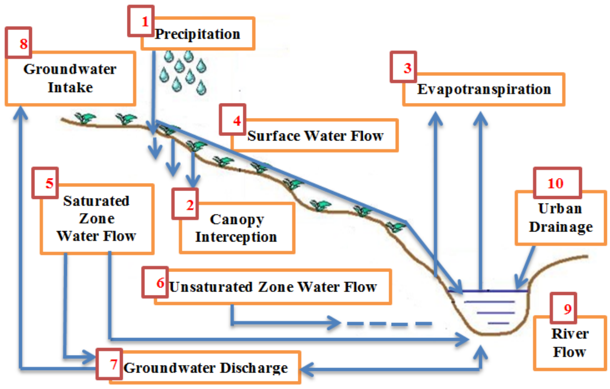

Figure 2: The concept of water management model in a river. Retrieved from http://www.ce.utexas.edu/prof/maidment/grad/samuels/txrr_proposal.htm

When raining, the rain water will drop and land on the Earth surface and be absorbed by the canopy before the excessive water enters the soil. There will be some water undergoing the evapotranspiration process and some water will flow as surface water entering the river. The excessive water that absorbed into soil will become groundwater, and this groundwater is clean and can supply drinking water. Before the existence of groundwater, there will be some excessive water forming as saturated zone water flow and unsaturated zone water flow. The saturated water and unsaturated water, together with groundwater will flow into one particular area, which is the river. However, the water flow in the river has the ability to exchange flowing direction with groundwater that results in a steady flow as proven through the calculation of Darcy's Law [12]. Since water resources from the groundwater or the river will be used to carry out any human activities (example residential or industrial), it is compulsory to have treatment towards the wastewater before it discharges into the river.

Site Selection

This review paper study is involved with a large watershed of river, such as Malacca River (figure 3). From the general view in the figure 3, there are many small channels or small rivers that are connected to the main river to form a large water catchment, and there are many activities are carry out in this watershed, such as agricultural activities, factories activities, residential areas, and so on. These activities are believed to become main factor that contribute water pollution in the Malacca River [9]. Therefore, an approach is required for using GIS applications for managing the water resources in the Malacca River.

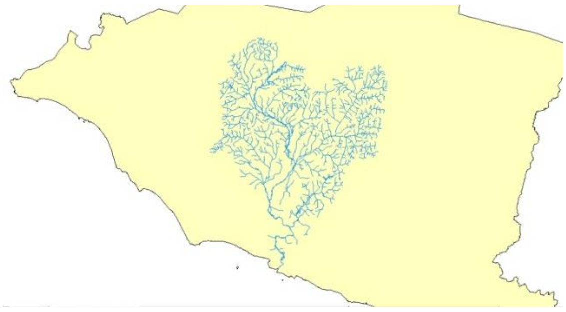

Figure 3: The watershed of Malacca River.
Retrieved from Department of Irrigation and Drainage Malaysia.

III. RESULTS AND DISCUSSION

As a result, application of GIS in sustainable water resources management in Malacca River may be explained according to figure 4 below.

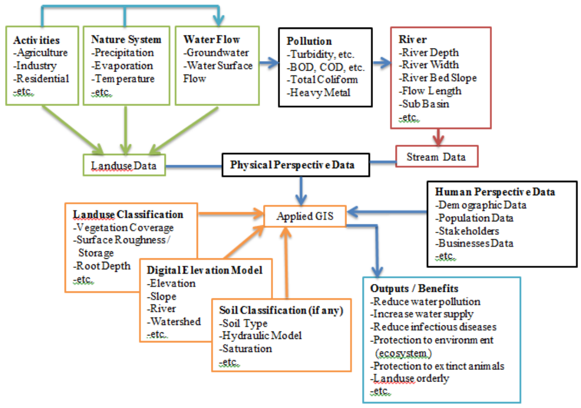

Figure 4: Physical and human perspective data for GIS analysis and the benefits of application GIS.

A. Preparation in GIS

Generally, GIS is a tool which helps the user in making decisions (planning, managing, etc.), data presentation (academician, lecturer, researcher, student, etc.), better recordkeeping (water flows, population census, land ownership, etc.), and so on [4]. Each new result or information will be provided in the form of geographical map. Therefore, as a user of GIS, there are several process to be determined from input (transfer file, digitize, key-in information, etc.), analyze (extract, overlay, proximity, statistic, etc.), and output (maps, charts, 3D maps, etc.).

Basically, a topography map (which exists in hardcopy form) will be scanned into softcopy and transferred into GIS for digitizing into a cartoon map (which exist as vector file in GIS). After the process of digitizing is conducted (including the mapping of buildings, rivers, roads, stations, etc.), the raw data, such as landuse data, stream data, water pollution data, population data, and so on, can be keyed into GIS as new information before undergoes any particular analysis to provide the results.

A. (a) Physical Perspective Data

I. Landuse Data

There are various natural environment processes that occur daily such as precipitation, evaporation, temperature, and so on which take the form of a system known as natural system. The process of precipitation will cause water surface or groundwater to flow in various directions before entering the river. This water flow will transport foreign substances together into the lower area or in the river. Since human activities including agriculture activities, industrial activities, residential activities, and urban development activities, among others, are carried out near to the river or in the boundary of river basin, these activities will result water pollution in the river such as turbidity, BOD, COD, total coliform, heavy metal, etc. Due to these conditions, the landuse data such as human activities data, nature system data, and water flow data can be overlapped together to determine suitability for any development to carry out in within the river basin or even near the river.

II. Stream or River Data

Since all water surface flow and groundwater flow will end up in the river, it is likely to cause water pollution in the river. Therefore, it is very important to have data like river depth, river width, river bed slope, river length, and the flow of the river, which can be used to determine factors in reducing the occurrence of water pollution. For example, the higher the slope, the faster the flow of water in the river. Thus, when water flow is rapid, there will be more foreign object such as sediment transported together (because of water transport energy increase due to the gradient increase). Plus, with a river's physical increase in depth, width, and length, this condition will result in increased water pollution especially the physical parameters pollution in river. This is because the river depth and width will determine the ability to accommodate more sediment in the river, and the river length will determine the distance for sediment to be transported along in the river. So, the river's physical characteristic data become a very useful data that can be overlap with the water pollution data to management on water resources in the river. For example, planting more trees and reducing land development can help in slowing the water flow into the river or in the river.

A. (b) Human Perspective Data

Water resources are asset for every human activity such as drinking, bathing, washing, catching fish as food sources, and so on. However, when water pollution in river exists, this situation not only stopping the activity, but also bring harms through various infectious diseases. Therefore, the government, the private (include stakeholders and business parties), and the local citizens should be involved in providing their perceptions and opinions toward water resources in the river. Hence, the data for water pollution in the river can be collected through questionnaires. Basically, the questionnaire is set into several parts, where the question will ask for demographic profile, perception toward water pollution, and opinion on management water resources in river. This information can be keyed into GIS to analyze together with the physical perspective data by overlap the data to provide new result, for example, the more settlement concentrated at a particular area will increase possibility water pollution through dumping of waste cooking oil or waste washing water into the river.

B. Processing and Benefits of GIS

After collecting all raw data from both a physical and human perspective, GIS has the ability to combine all the data and undergoes analysis together to provide new information for decision making in sustainable water resources management in Malacca River. Analyzing GIS through overlay methods between landuse data, stream data, and human data produces results in geographical map. For example, for any land development for particular activities near to the river (e.g. in distances lower than 5 km) at a high gradient with less vegetation coverage, this analysis will result a very high probability to contribute to water pollution in the Malacca River. In addition, the concentrated settlement of a particular area will increase the percentage of water pollution. Therefore, local communities involved in participating with their time and energy in answering the questionnaire will help a lot, especially in providing accurate information. This is because the local community's life experience and exposure, plus an optimum level of education, help a great deal in giving their perception and opinion towards the water pollution in Malacca River. Again, GIS has the ability to analyze this raw data through statistical analysis and provide an answer into graph or table in the form of geographical map.

The analysis indicates new results and these result become a benefit to GIS user in various field. Yet in the field of water resources, the purpose of GIS is to plan and manage water resources, especially in reducing river water pollution and improve water supply. GIS will manage to stop the pollution, and this will save aquatic animals from extinction and protect the environment from destruction. On the other hand, the reduction of river water pollution will also reduce the spread of infectious diseases and reduce the harm toward human. So, GIS has helped in solving the problems as a whole that occur in a particular area especially in managing river water resources.

IV. CONCLUSION

GIS contains friendly and flexible tools in helping the user in manage the environment, especially those involved with river water resources. Again, GIS is a power tool for developing solutions for water resources such as assessing water quality and managing water resources on local or regional scale. As discussed above, GIS technology has been applied to integrate with various data and analyze into one which is manageable system. For example, a hydrologists expert will use a GIS contained in Arc Hydro which is able to facilitate the creation, manipulation, and display the hydro features and objects within the ArcGIS tools. Meanwhile, water quality data are appropriate for input in GIS to manage both groundwater (which involve the recharge areas) and surface water (which involve the watershed or aquifers), such as for example the load. GIS has the ability to calculate the loads on a surface water body that cause water pollution to occur in a river. A load can be referred to as product of flow and concentration, which are also defined by how much mass of chemical indicators enters into a system for a specific of time. So, the load that exists in the water system can be determined as either coming from point sources such as industrial discharge or non-point sources such as agricultural runoff. Once the result of load in water body is known, the water quality model can be developed by determining the changes in the water body. So, the GIS tool has shown the ability to develop both load calculations and water quality models.

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