AN IMPROVED METHOD FOR WATERSHED MANAGEMENT - A CASE STUDY OF ARCGIS APPLICATION TO THE SKUDAI WATERSHED, MALAYSIA

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ABSTRACT: Geographical Information System (GIS) is an effective tool for watershed management as it is compatible to take multiple factors into its aggregation process and produce a solution which is very close to the optimal utilization of land and water resources. GIS has the capability of producing land use maps for better visualization of watershed problems which significantly improve our understanding of the watershed. This paper also presents a literature review on applications of Geographical Information System (GIS) for watershed management and also presents preliminary results of its application in the Skudai watershed where the whole watershed has been delineated to diagnose land use issues in the Skudai watershed. With the application of GIS to the Skudai watershed, it was easy for us to identify the sub-watersheds within the Skudai watershed. A total of 25 sub-watersheds were identified. Suggesting a remedial measure to a particular watershed problem became easier for smaller scale watershed rather than exploring the whole Skudai watershed. We have shown major land-use patterns of each of the sub-watershed. Compare to previous understanding of land and water resources in the Skudai watershed, the GIS results have improved our understanding of the watershed issues in a better and transparent way.

Keywords: Skudai watershed, Geographical Information System (GIS), Watershed alternative management, Delineation of watershed

1. INTRODUCTION

The watershed which is the area that captures water from various forms and drains it into a common water body is extremely important not only for humans but also for plants and animals [1]. Among the main functions of the watershed are collecting water from sources like rainfall and snowmelt, storing the water and discharge it to downstream. Most of our activities depend on watershed thus it is vital to keep our watersheds healthy and sustainable. Unfortunately, due to rapid developments, many watersheds all around the world (e.g., Chittagong Hill Tracts in Bangladesh, Yangtze River Basin in China and Bernam Watershed in Malaysia) are undergoing degradation and this causes problems such as the reduction of the quantity as well as the quality of water resources and deterioration of natural habitats [2-4]. Noticing the watershed problems that bring so much loss to human and the environment, many studies have been done to devise the effective watershed managements to prevent and mitigate the problems related to watersheds. In order to properly manage a watershed, thorough understanding and assessment of the watershed condition are required before planning the management strategies.

Geographical Information System (GIS) is a powerful tool in developing water resources solutions like assessing water quality and managing water resources on a local as well as regional-scale [5]. GIS can be used for data input, data storage and management, data manipulation and analysis and data output. It is proved to be a useful and efficient tool as it is capable of performing an integrated analysis of spatial and attribute data such as land use, population, topography, and hydrology where the data are manipulated and analyzed for obtaining the information required for particular application [6]. Due to this feature, GIS has been widely used as an approach for enhancing the effectiveness of watershed management as there are many factors and components in watersheds such as forest, land, water, soil, flora, fauna, people and animals that need to be considered for the management. It can also handle a large number of maps or data and combine them for better analysis. The data and maps that we want to use in watershed management will be more organized with the application of GIS where they can be integrated into one manageable

system. GIS is suitable to be used in many types of watershed analysis (e.g. spatial evaluation of erosions in watershed [7] and assessment of the relationship between land use and water quality [8]) where it can make the analysis process easier.

In watershed management, this tool is also useful in acquiring information such as the topography and the land use of the watershed which allow us to save time, money and energy for obtaining data especially when we are investigating a large watershed. Obtaining information is easier because we can extract a lot of information from GIS map layers. Sharing of information between different departments or even countries is further encouraged by the existence of GIS technology. Another GIS feature that makes it a valuable tool is its ability to be integrated with watershed modeling for solving problems geographically. Coupling GIS with an environmental model provides a tool to run a simulation and to interpret the results in a spatial context [9]. GIS also produces results or output in map or table forms that are more presentable and can be easily understood by stakeholders and decision-makers that often participate in watershed management. It provides a better perspective for understanding watershed problems.

Proper management of watershed requires delineation of the watershed for investigating its conditions in a detailed manner by comprehensively diagnosing the sub-watersheds in it. With the help of GIS software, delineation can be done in a shorter time with easier procedures. One of the GIS software that is widely used is ArcGIS. Watershed delineation by using GIS helps in analyzing the properties (e.g. land use, soil types, and slopes) of each sub-watershed thus letting us know the problem areas which are very important for management purpose and can provide sub-watersheds ranking. The ranking or prioritizing alternatives (i.e. the sub-watersheds) is preferred for finding the optimal solution in the case where budget and resources are limited [10]. Treatment can be done on the sub-watershed with the worse condition first before they turn unmanageable and bring problems the whole watershed. When the budget and resources are available, the next management can be done according to the rank and level of the watershed problem. Delineation of the watershed that leads to the prioritization approach has been applied in a number of studies in watershed management due to its effectiveness for solving watershed problems [11-17].

The approach has been used for identification and prioritization of critical sub-watersheds for soil conservation in Upper Damoder Valley Corporation. It employed GIS for generating the watershed and sub-watersheds boundaries, damage network, slope, soil series and texture maps [13]. In prioritization of water management for sustainability study,

Anyangcheon watershed was divided into four regions for calibration and verification of hydrologic simulation model in order to achieve a more precise simulation [10]. GIS has been found a useful tool in the identification and categorization of the watershed on the basis of natural resources and their limitation when it was used in combination with remote sensing for Guhiya watershed prioritization study. There are many other studies that employed GIS in watershed management field and it has proven its ability to successfully enhance the management. Due to the widespread applications of GIS in watershed management, this study uses GIS to investigate how the approach able to provide better management of Skudai watershed. GIS is used in the delineation of the watershed and acquiring watershed information. The output from GIS is analyzed for finding the problematic sub-watersheds for future management. Having all these benefits of GIS for watershed analysis and management, this tool was selected and applied to the Skudai watershed for fast identification of the watershed problem and devising mechanism or remedial measure to solve the problem within the shortest possible time.

2. METHODOLOGY

2.1 Study Area

Skudai watershed which located in Johor Bahru, Malaysia has the area of 31760 hectares. It is bounded by the latitutes 1° 28' N and 1° 49' and the longitudes 103° 29' E and 103° 43' E. It encompasses areas with rapid development such as Kulai, Senai, Tampot and Johor Bahru City. The rivers that are in this watershed are Danga River, Senai River, Melana River, Kempas River and Skudai River. The major problems identified in the Skudai Watershed are polluted rivers and flooding. Fig. 1 shows the location of the Skudai Watershed on the Malaysian geography map.

2.2 Application of ArcGIS to Delineate Skudai Watershed

The first step in applying GIS to the Skudai watershed was to delineate it into the number of sub-watersheds. The delineation and analysis of the Skudai watershed were done by using ArcGIS 10 software where Arc Hydro Tools was also added for application. Arc Hydro is a geospatial and temporal data model for water resource that operates within ArcGIS software [17-18].
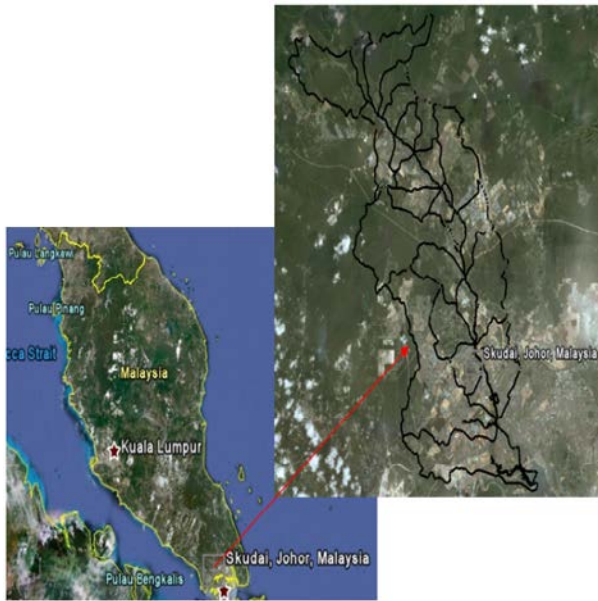
Fig.1 Location map of the Skudia watershed

2.2.1 Data source

Data needed for the application of ArcGIS 10 were the data elevation model (DEM) map and the land map of the Skudai watershed and these data were obtained from Federal Department of Town and Country Planning. The Skudai watershed DEM map was used for the delineation process where the watershed was divided into several sub-watersheds for better management and analysis. The map was then used in combination with land use and soil types layers in ArcGIS 10 for extracting the land use and soil types in the particular sub-watersheds so that the analysis and assessment in each Skudai sub-watershed can be done separately.

2.2.2 Delineation procedure

ArcGIS uses DEM for identifying drainage patterns and delineating watersheds which is defined as a grid or raster of square cells whose cell value is the land surface elevation in the center of cell. From the DEM or raster map of Skudai watershed, terrain pre-processing was done and the steps are shown in Fig. 2.
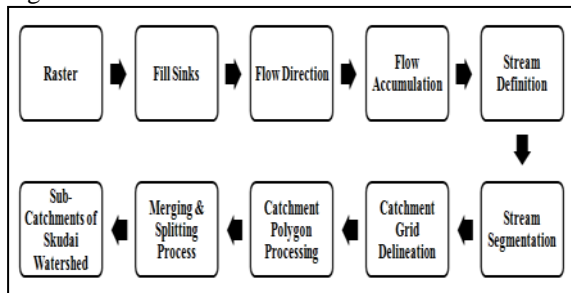

Fig.2 Pre-processing steps

All the steps must be done by following the correct sequence. The DEM or raster map must first be applied the function of Fill Sinks where the depressions that exist in the terrain were adjusted to match the elevation of its surrounding for ensuring that water can flow across the terrain surface. Problems will occur if we do not modify the elevation of the cells with higher elevation surrounding them where the water will be considered as being trapped in the cell. This step gave new elevation values to the cells. The next function which was Flow Direction computed the flow direction following the steepest flow path. The grid operation created flow direction grid from DEM grid. The flow direction grid cell values were actually the flow directions defined by the eight-direction pour point model. Once the Flow Direction step was done, the Flow Accumulation was determined. Flow accumulation grid records the number of the cells that drain into an individual cell in the grid [17]. The grid was obtained by calculating the flow into each cell where we accumulated the cells that flow into each downslope cell. This showed the runoff of rainfall direction in the watershed.

The terrain pre-processing also involved Stream Definition step. Steams may be defined through the use of a threshold drainage area or flow accumulation value [19]. We need to consider the size of our watershed for setting the threshold value. If we use small threshold value for a large watershed, the process will take longer time to complete whilst if we use the large value for a small watershed, we may not get the detail and nice output. Stream network which has the values of the previous grid (flow accumulation grid) that are higher than the threshold value was created in this step. Stream Segmentation step was then done to divide the stream network into individual segments which resulted in a grid of stream segments with unique identification. Another step done in terrain pre-processing was Catchment Grid Delineation where a grid with all cells having a grid code that indicated to which catchment the cells belonged was created. This grid which was in raster format was then converted into vector format in Catchment Polygon Processing step. Finally, Merging and Splitting step was done to improve the delineated watershed by either reducing or adding the number of sub-watersheds according to its suitability.

2.2.3 Integrating land-use layers

After generating the delineated Skudai watershed, it was added to ArcGIS 10 for analysis of the land use. The land use and was bounded to the watershed and sub-watersheds so that we could focus on those

without being affected by the areas outside the boundary.

3. RESULTS AND DISCUSSION

This section shows the results from ArcGIS 10 that was used as a means for delineating and analyzing the Skudai watershed. Analysis of every sub-watershed on the properties and land use is also discussed here. The advantages of applying GIS in this research are also discussed.

3.1 Delineation of the Skudai Watershed

Delineation of the Skudai watershed resulted in 25 sub-watersheds (Fig. 3). The nomenclatures (e.g. A, B, B1, B2, etc) assigned to the sub-watersheds were generated by the software thus they do not contain any information beyond these symbols. By having the small components of watershed, the analysis and assessment can be done in a better way where the properties of each sub-watershed can be scrutinized. Application of ArcGIS made the delineation process easy especially when the Arc Hydro tool was added where we just needed to follow the steps shown in the tool in sequence. However, the user must have some background on the theory and not simply clicking the steps in the software without knowing the function of the steps. Delineation process produced a map (Fig. 3) and some properties of every sub-watershed. The area (in hectare) for all the Skudai sub-watersheds can be seen in Table 1. The largest sub-watershed is the Melana River sub-watershed and the smallest one is B5. Having the information is an example of the benefit of using GIS in the study for acquiring information about the watershed. We did not have to measure the area of each of the sub-watershed. Time, energy and money can be saved by using the software. It also showed how convenient it was to share information where the DEM data of the Skudai watershed was shared by another researcher who worked on the same watershed but in a different direction.

3.2 Topography (slope) of the Skudai Watershed

Topography was generated by the elevation data of the Skudai watershed (Fig. 4). To investigate the topography, the highest slope for each sub-watershed was considered. Slope provides information about suitable land for development. Sloping areas show that the area absorbs less precipitation or runoff as water runs on the surface faster to the downslope area. The high velocity of faster running water will also contribute to erosion problem especially at looseand uncovered land. In Table 2, it can be seen that the highest slope of 39.3 possesses by sub-watersheds K, Senai, and the

Skudai Tributary. These sub-watersheds may have a higher chance of flooding and erosion especially if they have a high portion of uncovered land.
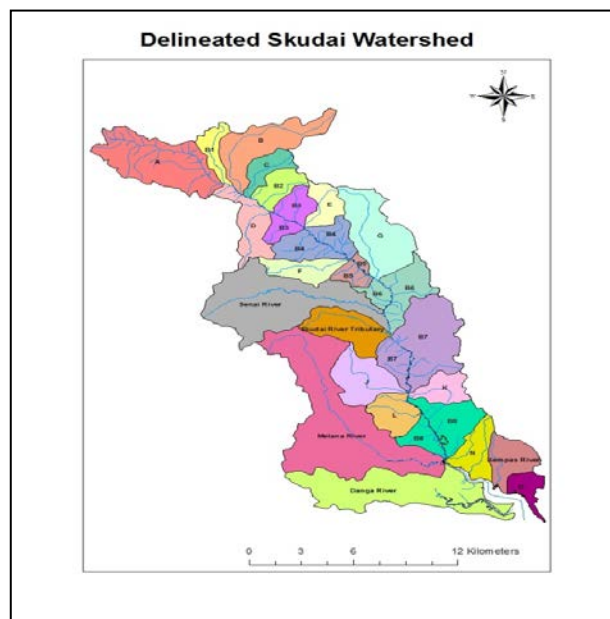

Fig.3 Sub-watersheds in the Skudai watershed

Table 1 Properties of the Skudai dub-watersheds

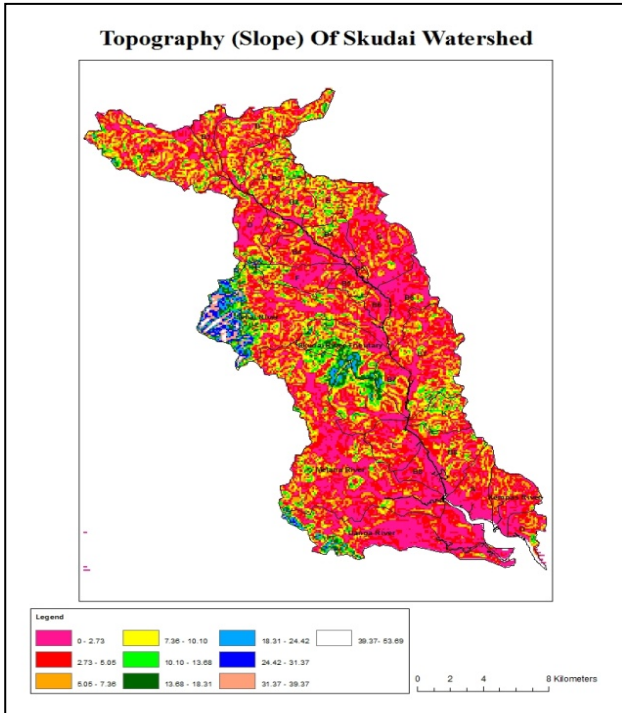| No.	Sub-Watershed	Area (ha)	No.	Sub-Watershed	Area (ha)
1	A	2151	14	E	524
2	B	1484	15	F	643
3	B1	424	16	G	1744
4	B2	540	17	J	1090
5	B3	729	18	K	556
6	B4	1053	19	Kempas River	758
7	B5	356	20	L	705
8	B6	1113	21	Melana River	4740
9	B7	2328	22	N	722
10	B8	1316	23	O	384
11	C	482	24	Senai River	3250
12	D	892	25	Skudai Tributary	1072
13	Danga River	2690			

Fig.4 Topography (slope) of the Skudai watershed

Table 2 Highest slope of the Skudai sub-watersheds

No.	Sub-Watershed	Highest Slope	No.	Sub-Watershed	Highest Slope
1	A	24.4	14	E	18.3
2	B	13.6	15	F	13.6
3	B1	18.3	16	G	13.6
4	B2	13.6	17	J	18.3
5	B3	24.4	18	K	39.3
6	B4	18.3	19	Kempas River	24.4
7	B5	18.3	20	L	13.6
8	B6	18.3	21	Melana River	24.4
9	B7	13.6	22	N	24.4
10	B8	18.3	23	O	53.6
11	C	18.3	24	Senai River	39.3
12	D	24.4	25	Skudai Tributary	39.3
13	Danga River	18.3			

3.3 Land use of the Skudai Watershed

The Skudai watershed consists of a variety of land use (Fig. 5).

Table 3 shows that sub-watershed B6 has a higher concentration of industries related infrastructures thus it must be observed to ensure that the industrial activities will not pollute the sub-watershed. Sub-watersheds that still have forest areas in them are A and Senai. With the total area of 4986.8 hectares, the forest in Senai sub-watershed must be protected for the sustainable environment of the whole watershed. The development of this sub-watershed that will require deforestation must be prevented. Knowing that the other sub-watersheds do not have forest area, reforestation can be done. The sub-watersheds A, B, B1, B2, B3, C, D, and E have large agricultural areas. It shows that they depend on agricultural activities. It can also be observed that only five sub-watersheds out of the total 25 watersheds had water bodies. Knowing the land use in every sub-watershed helps us to manage the watershed in a better way. It gives advantages especially in planning for the development. We are able to know which sub-watershed is suitable for development and which one is at risk due to urbanization or development.
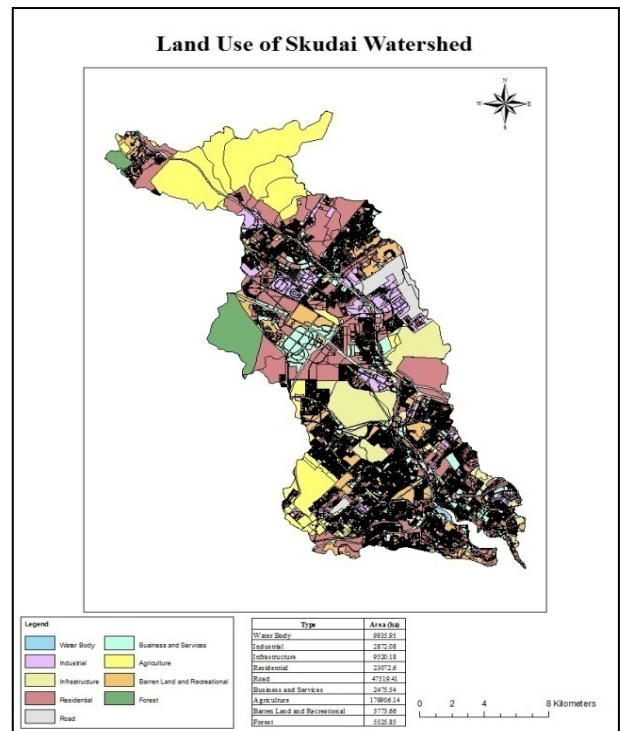

Fig.5 Land use of the Skudai watershed

Table 3 Land use of the Skudai watershed

N o.	Sub-Watershed	Area (in ha)								
		Water Body	Forest	Industrial	Infrastructure	Residential	Road	Business & Services	Agriculture	Barren Land & Recreational
1	A	0	539	4.4	16.4	956.9	344.2	9.48	23014.7	248.5
2	B	0	0	0	1.0	328.6	3.53	0.18	21829.4	0.35
3	B1	0	0	0	0	32.7	3.53	0	21829.4	0
4	B2	0	0	20.4	0	678.3	892.6	0	21829.4	0
5	B3	0	0	35.3	73.5	1202.8	1074.1	41.8	21833.5	15.3
6	B4	0	0	194.0	166.9	1425.1	1831.5	154.1	2.2	50.2
7	B5	0	0	191.8	49.3	157.7	3513.2	34.1	12.5	7.2
8	B6	0	0	436.0	1499.1	167.6	3795.6	73.6	63.5	12.5
9	B7	0	0	220.1	2536.8	1577.0	3038.7	26.7	53.4	78.4
10	B8	37.9	0	98.6	141.6	671.7	3190.1	230.2	1.3	317.7
11	C	0	0	20.4	0	318.6	0	0	21829.4	0
12	D	0	0	337.2	167.7	2878.9	2015.6	18.4	22956.3	40.3
13	Danga River	2473.5	0	104.6	187.6	189.1	2344.5	136.8	1008.6	569.8
14	E	0	0	48.9	14.9	1578.5	962.3	20.4	21830.8	6.83
15	F	0	0	26.1	127.6	349.9	1829.5	43.6	0	22.4
16	G	0	0	229.7	49.3	1286.3	4397.7	59.6	0	384.0
17	J	0	0	229.7	49.3	1286.3	4397.7	59.6	0	384.0
18	K	0	0	72.2	91.0	276.0	1686.1	60.2	0	165.5
19	Kempas River	2467.0	0	105.2	351.5	322.5	1194.7	98.1	0	23.3
20	L	0	0	0.24	329.3	263.0	716.2	70.4	6.73	67.1
21	Melana River	2490.2	0	199.4	1685.1	2076.0	4552.1	300.9	1742.1	653.2
22	N	2467.0	0	23.9	165.4	463.4	1697.3	149.7	0	70.9
23	O	0	0	7.95	193.6	191.1	1193.8	68.6	0	193.6
24	Senai River	0	4986	177.2	123.6	3614.1	1850.0	458.7	62.0	429.1
25	Skudai Tributary	0	0	88.0	1498.8	779.4	993.8	359.6	0.08	32.6

4. CONCLUSION

The application of GIS has proven a useful tool for managing watershed problems. This implied the relevance and suitability of combining GIS with the management of watersheds. In this study, we also delineated the Skudai Watershed to have close insight into land and water resources in the watershed. The delineation process resulted in 25 sub-watersheds within the Skudai Watershed. These sub-watersheds had the ranging area between 356 and 4740 hectares. The GIS application in the Skudai Watershed came up with land, water, soil type, topography parameters which are considered to be important parameters for managing any watershed. Skudai sub-watersheds B8 and N had about 38 ha and 2467 ha respectively covered with water. However, the remaining sub-watersheds had no water bodies. Industries were located in almost all sub-watersheds except for B and B1 where no industries were found. Forests were existing in A and Senai River sub-watersheds. More such data can be extracted from the sub-watersheds of the Skudai Watershed by the help of ArcGIS application. This work can be further extended in future by using GIS to the Skudai watershed for further division of the watershed based on thickness of the forest/canopy, population density, and such other similar parameters. This practice will ease watershed managers in suggesting better remedial measures if any problem was identified in the watershed.

5. ACKNOWLEDGEMENTS

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