Least-cost pipeline path to the Langkawi Island, Malaysia using a geographical information system (GIS).

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Introduction

A least-cost pipeline path simulation was performed on the two selected reservoir sites to selected targeted demand areas in the Langkawi Island, Malaysia. The selected reservoir sites were Ulu Melaka and Limbong (Wan Yusof and Baban 2000). In the development planning, future water supply requirement in the Langkawi Island will be targeted to major towns of Kuah and Temoyong. In this study, the work concentrated on finding the least-cost path to a major town (Kuah) and a new tourist area (Temoyong)

Physical factors and landuse/cover types

The least-cost pipeline routes to the two targeted areas (Kuah town and Temoyong resort areas) in the Langkawi Island can be influenced by land use, terrain, geological and environmental factors (Jankowski, 1995). Changes to these factors may incur higher cost such as trenching in consolidated rock, clearing of trees and shrubs, crossing of rivers or railways may require the building of bridges or supports to cross or pass through agricultural land (Feldman *et. al.,* 1996). Based on these facts, an analysis of the relationship between physical factors and land use/cover types for the whole of the Langkawi Island was performed (Table 1). Table 1 shows that land use/cover types under considerations were inland forest, rubber, mangrove, mixed horticulture, paddy and grassland. Information regarding their physical factors such as height, slope and geology and the percentage coverage for each factor were extracted from the digitised maps available for the Island. Using EXTRACT from the IDRISI function, a summary of data values for each class was extracted.

Table 1 also shows that about 88% of inland forest was within the highlands with altitudes between 20 and 400 m, slope of greater than 20^o and over 90% are on rock material foundations. Pipeline construction on highlands with rock materials such as granite, mudstone and limestone is difficult and in some cases blasting may be required, which will increase the cost (Feldman *et. al.,* 1996). On the contrary, construction on lower plains (between 0 and 30m) with gentle slopes of $0\text{-}2^o$, and the presence of alluvial material on paddy and grass will give easier access for the construction plants to manoeuvre and makes trenches. Mangrove areas are considered as an environmentally sensitive area (Feldman *et. al.,* 1996), so the possibility of pipelines crossing in this area could arouse conflict with environmentalist groups and therefore it was not considered to be viable.

Table 1 The analysis of the physical factors against the land use/cover types for the whole of the Langkawi Island.

Land use/cover	*Height (m)*	*% of range*	*Slope (degrees)*	*% of slope*	*Geology*	*% of geology*
Inland forest	20-400	88	0-40	81	Granite, mudstone and limestone	97
Rubber	11-70	84	0-8	80	Granite and mudstone; Alluvium	67 22
Mangrove	0-20	80	0-2	83	Alluvium; Limestone	59 33
Mixed horticulture	1-30	80	0-5	91	Alluvium; Granite and mudstone	53 37
Paddy	1-30	85	0-2	88	Alluvium; Granite and mudstone	58 40
Grass	0-20	82	0-2	92	Alluvium; Granite	68 18

The results of this analysis were used as the basis for determining a friction surface factor for the least-cost pipeline routes. The level of difficulty in crossing each land use/cover types under the influence of their physical factors determines the friction surface cost-value. For example, high relief terrain increases the cost of pipeline engineering and construction, and an unconsolidated fine-grained soil material is preferred to a rock surface because it does not require blasting (Janskowski and Richard, 1994; Janskowski, 1995; Feldman *et. al.*, 1996).

Friction surface

A friction surface which defined the costs associated with moving through different land use/cover types in the Langkawi Island was created (Table 2). This was based on the analysis of the level of difficulty of pipeline construction across the physical features as outlined in Table 1 together with the land use/cover types in the Langkawi Island. Grassland was taken as the base cost with a friction value of 1, because most of the grass areas were unmanaged and of low economic and environmental value. Subsequently, friction surface factors for other land use/cover types were also estimated relative to this base cost value. They included, in ascending order of friction surface value, mixed horticulture, paddy, and rubber. Due to poor economic returns and low yield values, many of the paddy fields have been abandoned (Langkawi District Council, 1992), so the cost of their land value was reduced to a friction surface value of 5.

Table 2 The relative costs of pipelines constructed through each of land use in the Langkawi Island.

Land use	Friction	Explanation
Waterbodies	1000	a very high cost-virtually a barrier
Inland forest	500	Passing through highlands
Mangrove forest	1000	Passing through salt marsh areas
Rubber	500	The trees felled, then removed
Paddy	5	Open space and abandoned land
Mixed horticulture	2	Less value
Grassland	1	Open space - base cost
Urban area	1000	a very high cost- virtually a barrier

Rubber is regarded as one of the commercial plantations covering 40.8% of agricultural land (Langkawi District Council, 1992), thus the compensation for cutting down rubber can be considerably higher (500 friction value). Some of the friction surfaces such as water bodies, salt-marsh mangrove and urban areas were very high (1000 friction value). This was to avoid passing through them but not totally prohibits their path in those regions (Eastman, 1997).

COST and PATHWAY functions in IDRISI allow the computation of the least-cost paths. The COST function calculates a distance surface where distance is measured as the least cost distance in moving over a friction surface. The PATHWAY function works by choosing the least-cost alternative each time it moves from one pixel to the next (Eastman, 1997).

Least-cost path

Based on the selected reservoir sites and the target areas, the proposed least-cost path for pipelines would be from the Ulu Melaka reservoir site (source cells) to Kuah town (destination cells) and from the Limbong reservoir site to Temoyong, one of the potential tourist resort areas.

Scenario 1

In the first analysis, the Ulu Melaka reservoir site, which was strategically located in the central region of the Island, was selected for the source cells and Kuah town in the south east region, was chosen for the destination cells. The cost distance analysis would need a friction surface that indicates the relative cost of moving through each cell. Using the COST function in IDRISI, a friction surface was then created for Kuah town (Fig.1).

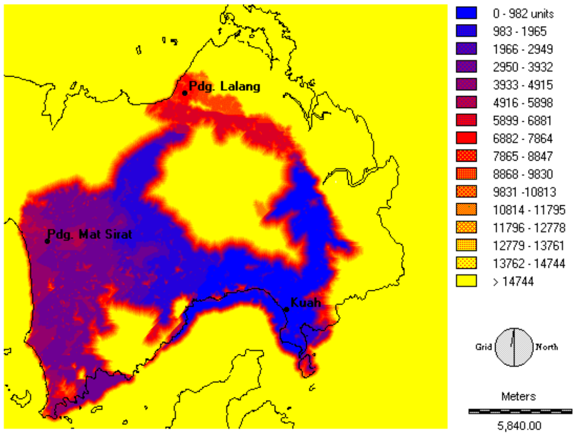

Fig.1

Fig.1 shows different colour tones of friction surface values of costs associated with the assigned land use/cover types friction values as in Table 2. Regions with darker tones show the areas with lowest friction surface values/costs and the lightest tone indicate areas with high cost. The lowest costs were in areas near to Kuah town as well as areas with grassland, paddy, and mixed horticulture. The moderate costs were in urban and rubber areas. The highest costs were in areas of inland forest, mangroves and water bodies. Consequently, using the PATHWAY function in IDRISI, the computation of the least-cost path was completed. The PATHWAY works by choosing the least-cost alternative each time it moves from one pixel to the next (Eastman, 1997). It will begin with cells along the dam and then continue choosing the least cost alternative until it connects with the lowest point on the cost distance surface of the town centre.

Similarly, the same procedures were applied to finding pipeline routes from the Limbong reservoir to Temoyong. Fig.2 shows the result of the least-cost pipeline routes from the Ulu Melaka reservoir to Kuah town and from the Limbong reservoir to Temoyong.

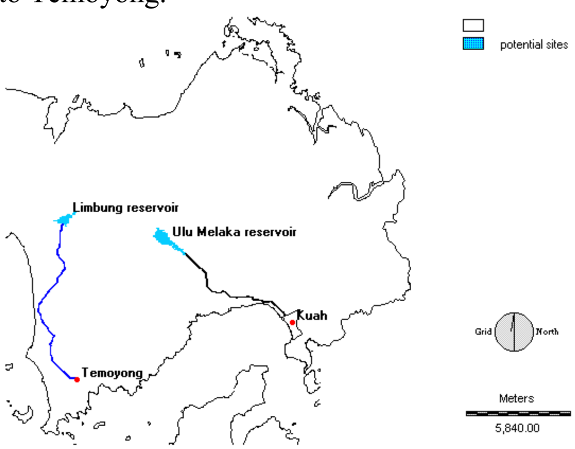

Fig.2

Scenario 2
There was a possibility that rubber may provide a lower friction surface value than paddy fields in cases where some paddy fields are regarded as reserved areas with high touristic value (Langkawi District Council, 1992). Alternatively, by changing the friction surface value of rubber from 500 to 5 and paddy from 5 to 100 respectively in Table 2, a new relative cost of pipelines were developed. Again, using the COST and PATHWAY functions in IDRISI and the same explanation for their application as discussed in the above scenario 1, the least-cost for both pipeline routes for scenario 2 were computed (Fig.3).

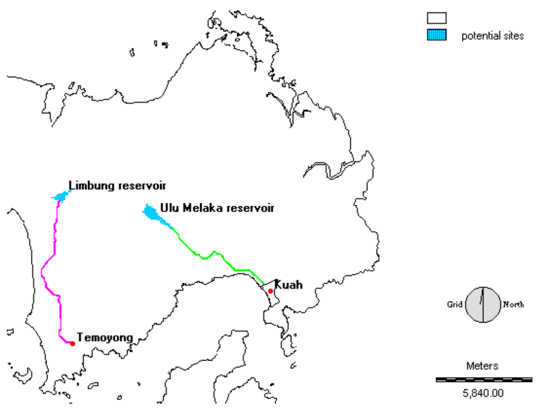

Fig.3

Result and analysis
Using the EXTRACT function in IDRISI, the lengths of the pipeline were determined (Tables 3 and 4). The EXTRACT developed the summary of statistics for the total pixels for the pipelines (Eastman, 1997) which were then converted to length by multiplying each pixel by 30 m. Table 3 and 4 show the result of pipelines for both scenarios 1 and 2 respectively.

In scenario 1, where friction surface values for paddy were lower than rubber, the least-cost pipeline distance from the Ulu Melaka reservoir to Kuah town was 6.57 km and from the Limbong reservoir to the Temoyong resort area, the distance was 9.12 km. In scenario 2, where friction surface values for rubber were lower than paddy, the least-cost pipeline distance was 6.3 km and 9.33 km respectively.

Table 3. Length of pipelines from reservoirs to the target areas in scenario 1.

Management scenario	Total pixels	Total length (km) (1 pixel = 30 metres)
Ulu Melaka reservoir to Kuah town	219	6.57
Limbong reservoir to Temoyong	304	9.12

Table 4. Length of pipelines from reservoirs to the target areas in scenario 2.

Management scenario	Total pixels	Total length (km) (1 pixel = 30 metres)
Ulu Melaka reservoir to Kuah town	210	6.3
Limbong reservoir to Temoyong	311	9.33

The effect of reducing friction surface values for rubber as in scenario 2, has decreased the pipeline length (from the Ulu Melaka reservoir to Kuah town) from 6.57 km to 6.33 km but the length (from the Limbong reservoir to Temoyong) has increased from 9.12 km to 9.33 km. This result suggested that reducing land use/cover type friction surface values may not necessarily decrease the pipeline length. It can also be deduced that other factors such as the position of each land use/cover types with respect to their adjacent land use/cover types may have influenced the least-cost pipeline distance.

Conclusion

The role of GIS for decision support for catchment management has been analysed. Several management scenarios are developed to provide alternatives to decision-makers. In the least-cost path analysis, two scenarios are presented; one based on a lesser value to paddy and the other based on a lesser value to rubber. Both scenarios produced similar results: the least-cost pipeline route to Temoyong was from the Limbong reservoir (9.12 km) for scenario 1 and to Kuah town was from the Ulu Melaka reservoir (6.3 km) from scenario 2. This study has shown that GIS can evaluate the suitable alternatives and visualise the results thus providing options to the decision-makers. Therefore, GIS, when reinforced by remotely sensed data, secondary data and field survey, can be a powerful tool for solving environmental problems in catchment management.

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