GIS Based Prescriptive Model for Solving Optimal Land Allocation

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Introduction

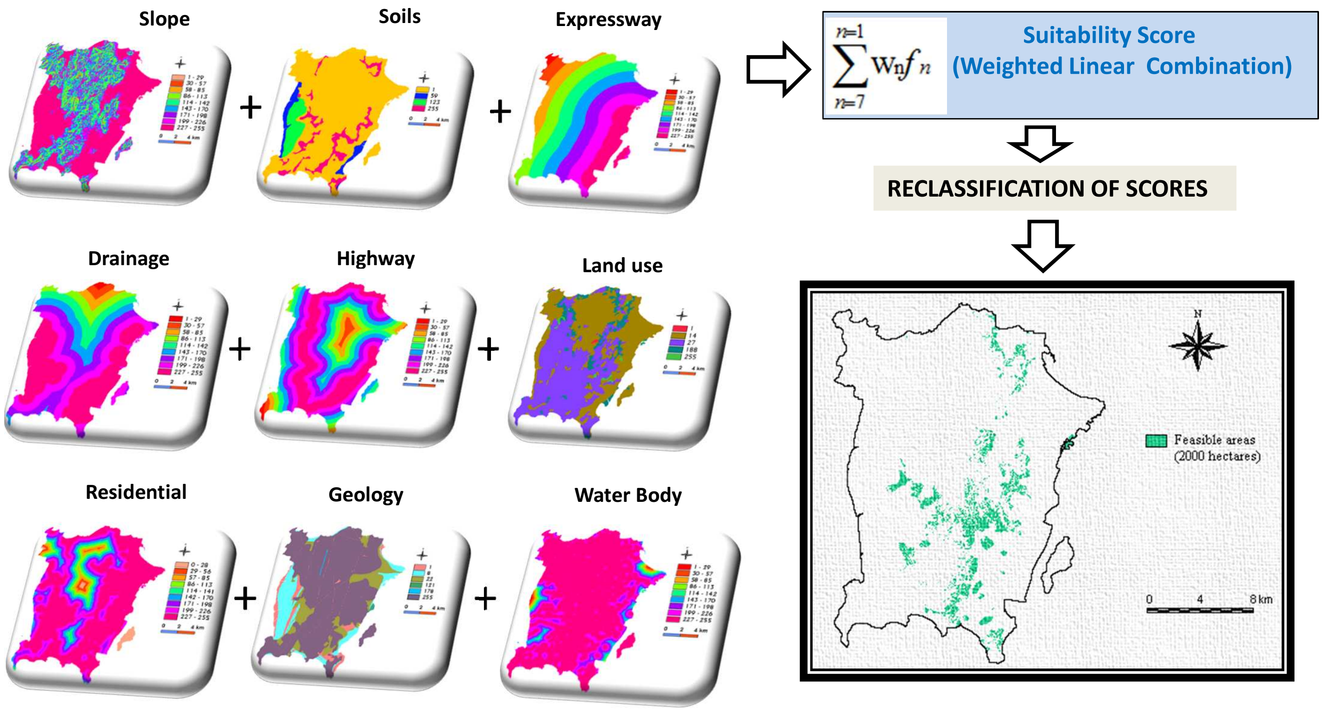
GIS LAND SUITABILITY MODEL

- Measure the relative usefulness of a land unit for some given purpose.
- Typically used to locate something (landfill, new settlement, industrial sites etc.)
- Model results in potential locations being identified and assigned a relative suitability score for the activity.
- Relative suitability defined on the basis of its physical, economic, social, and environmental characteristics.
- Ability to integrate decision maker's preferences addressed as decision analysis

A comprehensive and critical monograph surveys techniques for GIS-based suitability model. Such techniques include:-

- Boolean overlay operations for conjunctive and disjunctive screening of feasible alternatives (Malczewski, 2004),
- Weighted Linear Combinations, and Fuzzy Sets (Eastman, et al. 1995, 2005),
- Simple Additive Weighting (Malczewski, et al. 2002),
- Ideal Point Methods (Anchen, et al. 1997),
- Concordance Analysis (Joerin et al. 2001),
- Analytical Hierarchy Processes (AHPs) (Forman and Gass, 2001, Ahamad, et al. 2008)
- Ordered Weighted Averaging (Jiang and Eastman 2000).

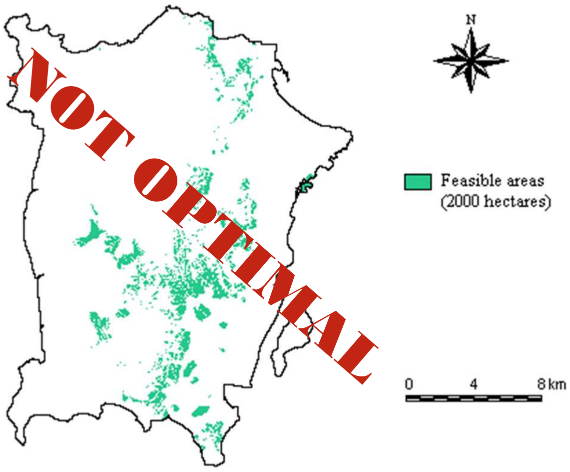
TYPICAL EXAMPLE OF GIS SUITABILITY MODEL
[SUM OF WEIGHTED FACTOR AND CONSTRAINT MAPS]



PROBLEM STATEMENT

The drawback of GIS suitability model is inability to determine most optimal sites amongst feasible locations.

The rule in selecting the most optimal site suitability model is could be of the choice function, i.e. provisions of mathematical means of comparing alternatives involving some form of Prescriptive Model



PRESCRIPTIVE MODEL

The rule in selecting the optimal area in a composite suitability map could be of the choice function i.e. using mathematical means of comparing alternatives.

They involve some form of optimisation, that require the evaluation of each alternative in turn and normally tackled by mathematical programming tools outside the GIS environment.

The general problem is the search for the optimum (maximum or minimum) from a function of variables constrained by equations or inequalities called constraints.

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PRESCRIPTIVE MODEL

In mathematical form, an optimization problem is viewed as finding the values for a set of decision variables in order to:

Optimize: $f(x_1, x_2, \ldots\ldots, x_n)$
Such that: $g(x_1, x_2, \ldots\ldots, x_n) \leq$ or = or $\geq b$
For i = 1, ……, m

where

- $f(x_1, x_2, \ldots\ldots, x_n)$ is some mathematical expression involving n decision variables,
- $g(x_1, x_2, \ldots\ldots, x_n)$ for i = 1 , ... , m represent the left hand sides of the m constraints,
- and b_i for i = 1 , ... , m are given fixed variables which occur on the right hand side of the m constraints.
- The condition, $x_j \geq 0$ for $j = 1,\ldots,n$ is usually added to the mathematical expression.

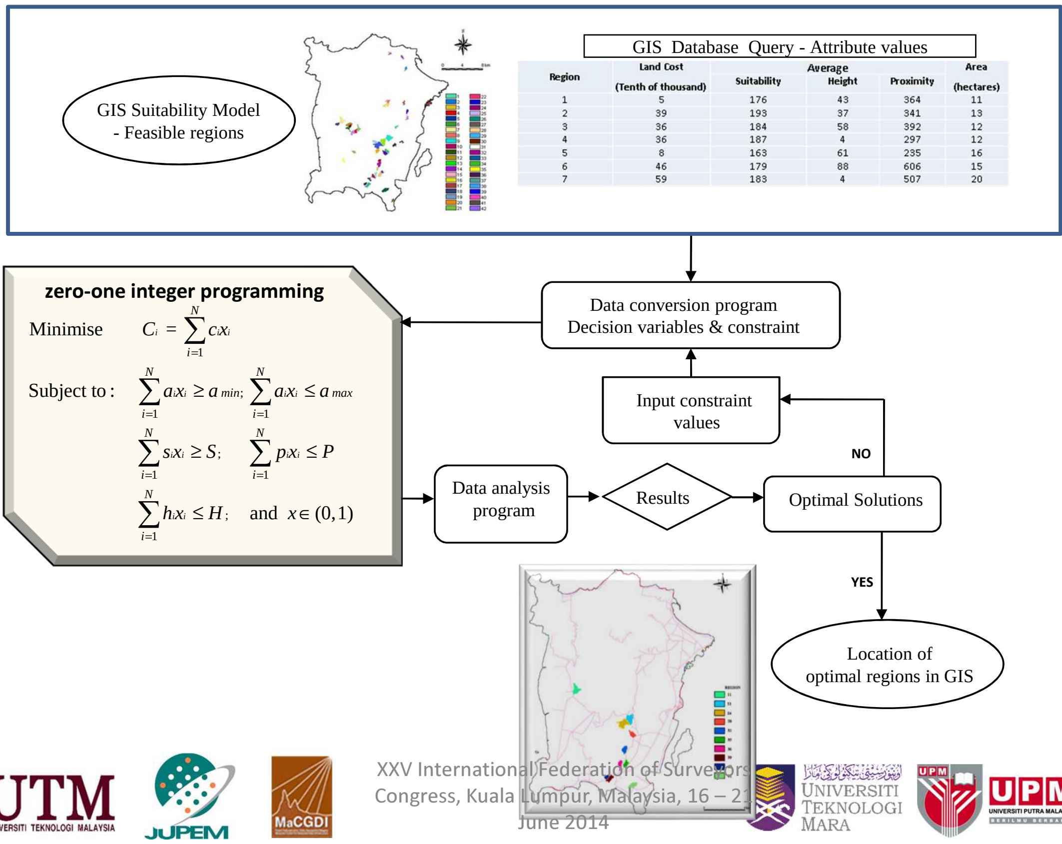
The optimal solution is values of decision variables that satisfy the constraints and for which the objective function attains a maximum (or minimum).

The optimization problems are not solved analytically but by means of explicit formula.

RESEARCH OBJECTIVE

- This research proposed GIS prescriptive modeling that incorporates mathematical programming techniques integrated with GIS.
- The research will attempt to formulate and solve optimal land allocation after normal GIS site suitability modelling.

MODEL IMPLEMENTATION



GIS Database Query - Attribute values

Region	Land Cost (Tenth of thousand)	Average Suitability	Average Height	Average Proximity	Area (hectares)
1	5	176	43	364	11
2	39	193	37	341	13
3	36	184	58	392	12
4	36	187	4	297	12
5	8	163	61	235	16
6	46	179	88	606	15
7	59	183	4	507	20

zero-one integer programming

Minimise $C_i = \sum_{i=1}^{N} c_i x_i$

Subject to : $\sum_{i=1}^{N} a_i x_i \geq a_{min}; \quad \sum_{i=1}^{N} a_i x_i \leq a_{max}$

$\sum_{i=1}^{N} s_i x_i \geq S; \quad \sum_{i=1}^{N} p_i x_i \leq P$

$\sum_{i=1}^{N} h_i x_i \leq H;$ and $x \in (0,1)$

MODEL FORMULATION

Minimise $$C_i = \sum_{i=1}^{N} c_i x_i$$

Subject to : $$\sum_{i=1}^{N} a_i x_i \geq a_{min}; \quad \sum_{i=1}^{N} a_i x_i \leq a_{max}$$

$$\sum_{i=1}^{N} s_i x_i \geq S; \quad \sum_{i=1}^{N} p_i x_i \leq P$$

$$\sum_{i=1}^{N} h_i x_i \leq H; \quad \text{and} \quad x \in (0,1)$$

C_i - the total land development cost,
N - the total number of feasible regions,
x_i - is 1 if allocate region *i*, and 0 otherwise,
c_i - the land cost of feasible region *i*,
a_i - the area of feasible region *i*,
a_{max} - maximum required area,
a_{min} - minimum required area,
s_i - the average suitability value of feasible region *i*,
S - the total maximum suitability value required,
P - the minimum total proximity achievable, and
H - the minimum total average height of selected regions.

1. The objective of equation is to MINIMISE the total land development cost of the regions allotted.
2. The area constraints limit the total area of regions to be allocated, the proximity and height constraints ensures that the regions selected will be nearest to transportation and lowest in heights, and the suitability constraint maximised the total average suitability value (suitability index) of the regions.
3. The model will identify a set of optimal feasible regions that satisfy the objective function and constraints.

Data format for Algorithm 1

MIN: 19 x1 + 28 x2 + 7 x3 + 14 x4 + 116 x5 + 8 x6 + 8 x7 + 215 x8 + 7 x9 + 117 x10 + 141 x11 + 100 x12 + 19 x13 + 33 x14 + 19 x15 + 27 x16 + 20 x17 + 65 x18 + 29 x19 + 59 x20 + 43 x21 + 29 x22 + 28 x23 + 15 x24 + 10 x25 + 6 x26 + 20 x27 + 34 x28;
c1: 20 x1 + 20 x2 + 14 x3 + 24 x4 + 22 x5 + 15 x6 + 15 x7 + 136 x8 + 13 x9 + 19 x10 + 15 x11 + 43 x12 + 35 x13 + 59 x14 + 14 x15 + 11 x16 + 13 x17 + 55 x18 + 51 x19 + 21 x20 + 60 x21 + 39 x22 + 20 x23 + 20 x24 + 17 x25 + 12 x26 + 37 x27 + 66x28 <= 500;
c2: 206 x1 + 224 x2 +205 x3 + 205 x4 +211 x5 + 205 x6 + 204 x7 + 204 x8 + 202 x9 + 210 x10 + 214 x11 + 210 x12 + 203 x13 + 218 x14 + 218 x15 + 203 x16 + 203 x17 + 206 x18 + 203 x19 + 203 x20 + 205 x21 + 215 x22 + 204 x23 + 215 x24 + 204 x25 + 215 x26 + 215 x27 + 198 x28 >= 3000;
c3: x1 + x2 + x3 + x4 + x5 + x6 + x7 + x8 + x9 + x10 + x11 + x12 + x13 + x14 + x14 + x15 + x16 + x17 + x18 + x19 + x20 + x21 + x22 + x23 + x24 + x25 + x26 + x27 + x28 <= 15;
c4:x1 <= 1;
c5:x2 <= 1;
c6:x3 <= 1;
c7:x4 <= 1;
c8:x5 <= 1;
c9:x6 <= 1;
c10:x7 <= 1;
c11:x9 <= 1;
c12:x8 <= 1;
c13:x10 <= 1;
c14:x11 <= 1;
c15:x12 <= 1;
c16:x13 <= 1;
c17:x14 <= 1;
c18:x15 <= 1;
c19:x16 <= 1;
c20:x17 <= 1;
c21:x18 <= 1;
c22:x19 <= 1;
c23:x20 <= 1;
c24:x21 <= 1;
c25:x22 <= 1;
c26:x23 <= 1;
c27:x24 <= 1;
c28:x25 <= 1;
c29:x26 <= 1;
c30:x27 <= 1;
c31:x28 <= 1;
c32: 20 x1 + 20 x2 + 14 x3 + 24 x4 + 22 x5 + 15 x6 + 15 x7 + 136 x8 + 13 x9 + 19 x10 + 15 x11 + 43 x12 + 35 x13 + 59 x14 + 14 x15 + 11 x16 + 13 x17 + 55 x18 + 51 x19 + 21 x20 + 60 x21 + 39 x22 + 20 x23 + 20 x24 + 17 x25 + 12 x26 + 37 x27 + 66x28 >= 450;
int x1 x2 x3 x4 x5 x6 x7 x8 x9 x10 x11 x12 x13 x14 x15 x16 x17 x18 x19 x20 x21 x22 x23 x24 x25 x26 x27 x28;

F1 — Area (hectares)

	A	B	C	D	E	F
1	Selected Region	Land cost (RM)	Average suitability	Average height (m)	Average proximity (m)	Area (hectares)
2	1	5	176	43	364	11
3	2	39	193	37	341	13
4	3	36	184	58	392	12
5	4	36	187	4	297	12
6	5	8	163	61	235	16
7	6	46	179	88	606	15
8	7	59	183	4	507	20
9	8	14	159	82	320	28
10	9	7	170	76	842	14
11	10	7	184	61	1209	14
12	11	24	170	24	392	48
13	12	8	168	23	167	16
14	13	11	154	27	956	21
15	14	7	151	24	889	14
16	15	13	168	67	1200	27
17	16	6	160	270	1144	12
18	17	8	166	28	440	16
19	18	9	168	34	765	17
20	19	11	172	36	448	23
21	20	30	160	125	357	50
22	21	31	170	66	325	51
23	22	12	149	168	310	24
24	23	5	190	49	553	10
25	24	48	169	95	725	67
26	25	9	195	76	884	17
27	26	22	177	20	209	22
28	27	11	182	97	1005	23
29	28	28	183	20	311	28
30	29	7	165	88	608	15
31	30	7	163	33	138	14
32	31	6	175	47	556	11
33	32	15	181	53	294	31
34	33	5	174	36	352	10

Data / Test 1 / Test 2 / Test 3 / Answer Report 1 / Test 4 / Test 5 / Test 6

Ready

J36

	A	B	C	D	E	F	G
19	18	0	168	34	765	17	9
20	19	0	172	36	448	23	11
21	20	0	160	125	357	50	30
22	21	1	170	66	325	51	31
23	22	0	149	168	310	24	12
24	23	0	190	49	553	10	5
25	24	1	169	95	725	67	48
26	25	0	195	76	884	17	9
27	26	0	177	20	209	22	22
28	27	0	182	97	1005	23	11
29	28	1	183	20	311	28	28
30	29	0	165	88	608	15	7
31	30	0	163	33	138	14	7
32	31	0	175	47	556	11	6
33	32	1	181	53	294	31	15
34	33	0	174	36	352	10	5
35	34	0	192	19	180	10	10
36	35	1	183	18	169	26	26
37	36	1	193	34	210	25	12
38	37	0	181	33	458	19	10
39	38	0	173	35	394	15	8
40	39	1	175	39	164	25	13
41	40	1	181	29	169	14	7
42	41	1	180	18	358	38	38
43	42	0	154	66	1069	13	7
44							
45	LHS Value	10	1785	396	3117	353	242
46							
47						350	
48	RHS Value	10	1,783	482	3,131	400	
49							

MS Excel SOLVER

G46 | f_x =SUMPRODUCT(B2:B44,G2:G44)

	A	B	C	D	E	F	G
16	15	0	27	168	67	1,200	13
17	16	0	12	160	270	1,144	6
18	17	0	16	166	28	440	8
19	18	0	17	168	34	765	9
20	19	0	23	172	36	448	11
21	20	0	50	160	125	357	30
22	21	1	51	170	66	325	31
23	22	0	24	149	168	310	12
24	23	0	10	190	49	553	5
25	24	1	67	169	95	725	48
26	25	0	17	195	76	884	9
27	26	0	22	177	20	209	22
28	27	0	23	182	97	1,005	11
29	28	1	28	183	20	311	28
30	29	0	15	165	88	608	7
31	30	0	14	163	33	138	7
32	31	0	11	175	47	556	6
33	32	1	31	181	53	294	15
34	33	0	10	174	36	352	5
35	34	0	10	192	19	180	10
36	35	1	26	183	18	169	26
37	36	1	25	193	34	210	12
38							
39	37	0	19	181	33	458	10
40	38	0	15	173	35	394	8
41	39	1	25	175	39	164	13
42	40	1	14	181	29	169	7
43	41	1	38	180	18	358	38
44	42	0	13	154	66	1,069	7
45							
46	LHS Value	10	353	1,785	396	3,117	242
47							
48	RHS Value	10	350	1,783	482	3,131	
49			400				

Solver Parameters

Set Target Cell: $G$46
Equal To: Max / Min (selected) / Value of: 0
By Changing Cells: $B$2:$B$44

Subject to the Constraints:
- $B$2:$B$44 = binary
- $B$2:$B$44 = integer
- $B$46 = $B$48
- $C$46 <= $C$49
- $C$46 >= $C$48
- $D$46 >= $D$48

Solve | Close | Guess | Options | Add | Change | Delete | Reset All | Help

Target Cell (Min)

Cell	Name	Original Value	Final Value
$G$45	LHS Value Cost	0	242

Constraints

Cell	Name	Cell Value	Formula
$B$45	Decision	10	$B$45=$B$47
$C$45	Area	353	$C$45<=$C$48, $C$45>=$C$47
$D$45	Suitability	1,785	$D$45>=$D$47
$E$45	Height	396	$E$45<=$E$47
$F$45	Proximity	3,117	$F$45<=$F$47

Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Test 7 | Test 8 | Test 9 | Answer Report 1 | Test 10

FIG

RESULTS OF ZERO-ONE INTEGER PROGRAMMING MODEL (MS EXCEL Solver)

Test	ΣSuitability Setting	ΣSuitability Result	ΣHeight Setting	ΣHeight Result	ΣProximity Setting	ΣProximity Result	ΣArea Setting	ΣArea Result	ΣCost	10 selected Regions
1	≥1885	1729	≥174	694	≥1935	5048	350 -400	350	198	8,15,19,20,21,24,27,32,36,39
2	≥1730	1734	≤693	605	≤5047	4962	350 -400	350	198	9,11,15,19,20,21,24,32,36,40
3	≥1735	1744	≤694	575	≤4961	4387	350 -400	350	199	11,12,15,20,21,23,24,32,36,39
4	≥1745	1747	≤574	548	≤4386	3737	350 -400	350	199	1,11,19,20,21,24,32,36,37,39
5	≥1748	1752	≤547	534	≤3736	3542	350 -400	353	201	11,19,20,21,24,32,36,37,39,40
6	≥1753	1757	≤533	518	≤3541	3303	350 -400	352	212	11,20,21,24,26,32,36,37,39,40
7	≥1758	1763	≤517	516	≤3302	3263	350 -400	356	216	11,20,21,24,32,35,36,37,39,40
8	≥1764	1764	≤515	486	≤3262	3177	350 -400	350	223	11,12,20,21,24,32,34,36,40,41
9	≥1765	1782	≤485	483	≤3176	3132	350 -400	350	231	11,20,21,24,28,32,34,35,36,40
10	≥1783	1785	≤482	396	≤3131	3117	350 -400	353	242	11,21,24,28,32,35,36,39,40,41
11	≥1786	1786	≤395	395	≤3116	3116	350 - 400	350	239	11,21,24,28,32,35,36,39,40,41
12	≥1786	1786	≥395	487	≤3116	3093	350 -400	351	251	20,21,24,28,32,34,35,36,39,41
13	≤1786	1772	≤395	390	≤3116	3115	350 -400	355	243	11,12,21,24,28,32,35,36,39,41
14	≥1786	1787	≤395	377	≥3116	3162	350 -400	350	251	11,21,24,26,28,32,35,36,40,41

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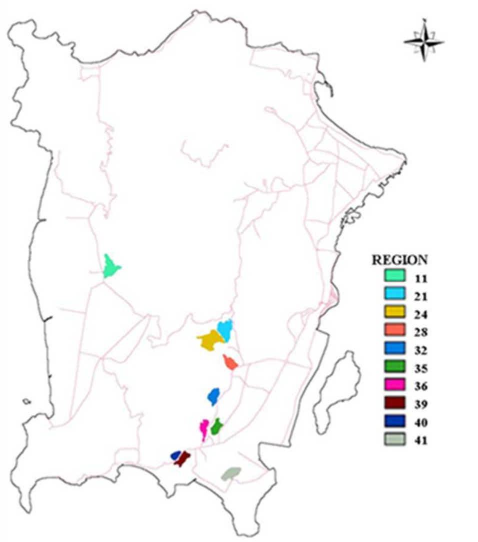
Mixed Integer Branch And Bound Algorithm in turbo C++ contributed by Eindhoven University of Technology, Netherlands (Notebaert, and Eikland, 2008).

Test	Σ Suitability		Σ Height		Σ Distance		Σ Area		10 Selected Regions	Σ Cost
	Setting	Result	Setting	Result	Setting	Result	Setting	Result		
1	≤ 1885	1729	≥ 174	694	≥ 1935	5048	350-400	350	8, 15, 19, 20, 21, 24, 27, 32, 36, 39	198
2	≥ 1730	1731	≤ 693	581	≤ 5047	4363	350-400	350	11, 12, 17, 19, 20, 21, 24, 27, 32, 36	198
3	≥ 1732	1747	≤ 580	548	≤ 4362	3737	350-400	350	1, 11, 19, 20, 21, 24, 32, 36, 37, 39	199
4	≥ 1748	1752	≤ 547	534	≤ 3736	3542	350-400	353	11, 19, 20, 21, 24, 32, 36, 37, 39, 40	201
5	≥ 1753	1757	≤ 533	518	≤ 3541	3303	350-400	352	11, 20, 21, 24, 26, 32, 36, 37, 39, 40	212
6	≥ 1758	1763	≤ 517	516	≤ 3302	3263	350-400	356	11, 20, 21, 24, 32, 35, 36, 37, 39, 40	216
7	≥ 1764	1764	≤ 515	486	≤ 3262	3177	350-400	350	11, 12, 20, 21, 24, 32, 34, 36, 40, 41	223
8	≥ 1765	1782	≤ 485	483	≤ 3176	3132	350-400	350	11, 20, 21, 24, 28, 32, 34, 35, 36, 40	231
9*	≥ 1783	1785*	≤ 482	396*	≤ 3131	3117*	350-400	353*	11, 21, 24, 28, 32, 35, 36, 39, 40, 41	242*
10	≥ 1786	1786	≥ 395	487	≤ 3116	3093	350-400	351	20, 21, 24, 28, 32, 34, 35, 36, 39, 41	251
11	≤ 1786	1772	≤ 395	390	≤ 3116	3115	350-400	355	11, 12, 21, 24, 28, 32, 35, 36, 39, 41	243
12	≥ 1786	1787	≤ 395	377	≥ 3116	3162	350-400	350	11, 21, 24, 26, 28, 32, 35, 36, 40, 41	251

ATTRIBUTES OF 10 MOST OPTIMAL REGIONS

Region	Suitability	Heights (m)	Proximity (m)	Area (Hect.)	Land Cost (* 10th Thousand)
11	170	24	392	48	24
21	170	66	325	51	31
24	169	95	725	67	48
28	183	20	311	28	28
32	181	53	294	31	15
35	183	18	169	26	26
36	193	34	210	25	12
39	175	39	164	25	13
40	181	29	169	14	7
41	180	18	358	38	38
Total	**1785**	**396**	**3117**	**353**	**242**



SENSITIVITY OF PRESCRIPTIVE MODEL

Sensitivity Tests on

- The effect of changes in the right-hand side value on certain constraints
- The effect of changes in the coefficients of the objective function
- The effect of changes in the coefficients of certain constraints values
- The effect when the constraints are reduced from the original problem

Condition	Area					Selected regions							
Ten optimal regions	242	11	21	24	-	28	-	32	35	36	39	40	41
Unspecified region	242	11	21	24	-	28	-	32	35	36	39	40	41
Reduced constraint	118	-	-	-	26	-	30	-	35	36	39	-	41

Objective Function	Optimum Regions											
Cost	11			21	24		28	32	35	36	39	40	41
Suitability	11	12		21	24	26	28	32		36	39		41
Proximity	11		19	21	24		28	32		36	39	40	41
Similarities	11			21	24		28	32		36	39		41

CONCLUSION

- Prescriptive model is capable of producing optimal feasible regions based on the objectives and constraints initially set in the allocation problem.
- The model is not sensitive to the number of constraint condition imposed on the problem but is sensitive to the changes made on the constraints indicating the importance of choosing a correct value for the constraints.
- Prescriptive model can be integrated with GIS suitability model [loose coupling] in finding the optimal solution for a spatial site selection problem

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Thank you for your attention!

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