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Multi-Criteria Group Decision-Making (MCGDM) for Verification of HydroGIS Model Development Framework

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Abstract *Expert review is the best method for the verification of flood management frameworks. However, when verifying a building-block software framework for urban flood management HydroGIS model development (HydroGIS Framework), the framework is always subjected to more arguable or marginal acceptance, due to the development process is less observed by the expert evaluators and a higher possibility of localised thinking limited to experts' field of studies. Therefore, in such scenarios, the multi-criteria group decision-making (MCGDM) method gets popular as it mainly analysis the group of experts' view on a set of alternatives (options) following the same set of criteria. However, the MCGDM method directly does not support the present verification. Therefore, the present work aims to modify the MCGDM method for verification of the present HydroGIS framework. For that, it studied different works on MCGDM and formulate a general map of integrated processes. Then analyse the HydroGIS framework components' integration depths using spatial analysis method (area comparison) and attention theory explanation, to select a suitable fuzzy type to be used in MCGDM. After that present work map, the framework verification attributes to the MCGDM model and carry out the verification. As result, it developed a verified relation map of various fuzzy concepts, formulated a generalised process map of the MCGDM process, identified Type-1 fuzzy concept is substantial to expert preferences demodulation and demonstrated how it can employ modified MCGDM method to evaluate the urban flood management framework satisfactorily. The present work shows how MCGDM can be utilised for Flood management framework verification.*

***Keywords*— Multi-Criteria Group Decision-Making (MCGDM), HydroGIS Tool, Urban Flood Management Framework, Fuzzy Concept, Expert Review**

I. INTRODUCTION

A. Background

The early work of the authors developed the urban flood management HydroGIS model development framework which can be utilised by the software professional (Pradeep & Wijesekera, 2021). It is categorised under the building-block software framework category (Pradeep & Edirisuriya, 2021) where the transdisciplinary approach is highly employed in development. The development of the framework, syntheses the knowledge and experiences of multiple experts such as government administrators, water and civil engineers, land, town and city planners, policymakers, lawyers, socialists, economists and environmentalists. Then, based on the research articles on the components of the framework, it calculated the integration depths as shown in Figure 1. These integration depths varying from 0 to 5 (the number with decimal points on the arrow) denote the attention of the researchers on the components when developing the urban flood management model (0 denotes no integration, 1 denotes totally integrate). As well the components which are shown in the rectangles show the generalised components in a building-block software framework.

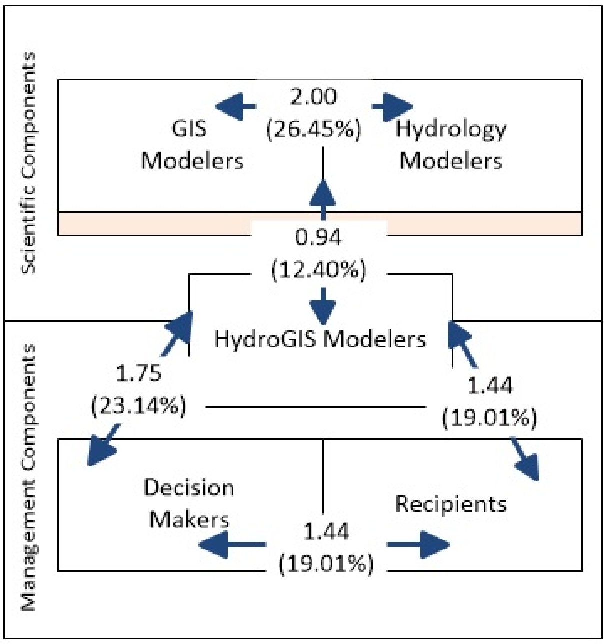

Figure 1: The Average Depth of Investigation in Each Integration and its Comparison Level as a Percentage
Source: (Pradeep & Wijesekera, 2021)

B. Flood Management Framework Verification

The practical implementation of flood management frameworks and analysis of its outcome are time-consuming. Hence, most researchers evaluate the developed frameworks through expert review (Malalgoda et al., 2013; Molinari et al., 2017, 2018). However, foresaid HydroGIS model development framework is a suggested solution through an abductive theory approach with interpretivism philosophy. Due to this phenomenal continuum, the solutions may be subjected to more arguable as the development process is

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less observed by the expert evaluators and higher possibility of localised thinking limited to the own field of study (Lane et al., 2020). Specially, as the solution is suggested to integrate multiple disciplines which inherently creates conflict in the epistemic values, the marginal acceptance of the framework is predictable (Huutoniemi, 2010; MacLeod, 2018).

C. Multi-Criteria Decision-Analysing (MCDA)

Therefore, in such a scenario, if it gets the expert reviews and analysis them using symmetrical methods such as correlation and coefficient of determinations may misinterpret the real feeling of the evaluators and ignores the influences of different knowledge depending on the factors (Woodside, 2013). Further the demodulation of individual analogue reviews (preferences) to digital may distort the real mood of the preference. Therefore, as MCDA evaluates the different evaluators' opinions, the present work studied the different MCDA methods and found that multi-criteria group decision-making (MCGDM) is interesting to present work. MCGDM mainly analysis the group of experts' views on a set of alternatives (options) under the influence of the same set of criteria. When considering the HydroGIS model development framework, the framework and its components' integration depths may be evaluated by different experts heterogeneously. Therefore, due to the power of MCGDM to settle the conflicting decision-making criteria and synthesis the processes of different individual experts (Morente-Molinera et al., 2020; Naim & Hagras, 2014), it identified that MCGDM is the best-suited method for analysis the experts' reviews on the developed framework. However, there is no direct guideline for utilising MCGDM in the same work.

A. Aim

Therefore, the present work aims to study the MCGDM methodology and employ it for HydroGIS model development framework verification.

II. ANALYSIS

A. Multi-Criteria Group Decision-Making (MCGDM)

When studying the MCGDM, it found that there are number of different employments of the method. Then, it studied the works of Naim and Hagras, (2014), Çağman and Karataş, (2013), Das, Kar and Pal, (2014), Rahman et al., (2021) and Morente-Molinera et al., (2020) and observed that those are tailored developed based on the individual requirement of the study. Then the present work generalised the inputs, processes and outputs of those methods and identified 7 components in the processes as shown in Figure 2.

In this generalised MCGDM scenario, the preferences of a group of experts on a set of alternatives are evaluated to make a final decision. Then in the process, a number of experts (1 in Figure 2) are expressing different preferences (2 in Figure 2) on the alternatives or solutions available (3 in Figure 2). However, the experts' preferences are influenced by different criteria (4 in Figure 2). Then either analysing a simple expert review or employing an individual fuzzy logic-based method (6 in Figure 2) it attempts to generalise the final decision as a ranked list or prioritized item of alterative/s (7 in Figure 2). Then when considering the employed fuzzy logic-based method, evaluated works presented different methods such as single-valued neutrosophic (SVNS), interval neutrosophic (INS), and interval-valued intuitionistic fuzzy (IVIFS) which the attention of the present research was grabbed.

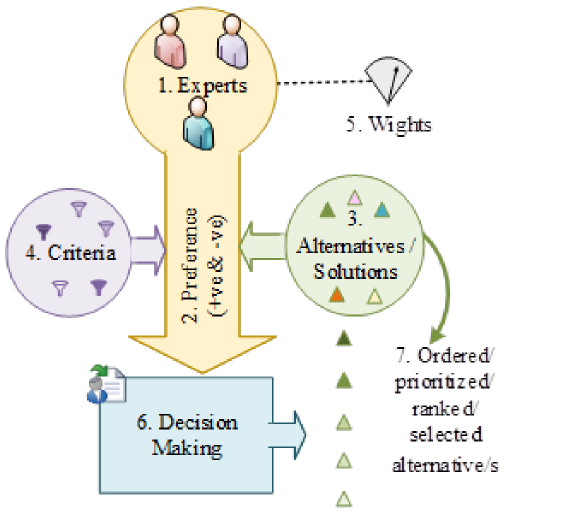


Figure 2: Generalized Multi-Criteria Group Decision-Making Processes Map

B. Integration of Fuzzy Concept

Then it studied the role of the fuzzy concept in MCGDM and found that to reduce the demodulation-distortion that happens in expert review analysis, it utilises the knowledge of the fuzzy concept as the fuzzy concept evaluates all possible indicators to measure the level of preferences in multicriteria affecting situations (Sahani et al., 2019). Then it carried out a study on the concept and found that there are 6 methods which are based on type-1, type-2, Hesitant, Intuitionistic, Neutrosophic or Plithogenic fuzzy concepts (Kaya et al., 2019; Smarandache, 2018). The evolution of concept is described differently, hence it developed a generalised flowchart of the concept building. It contacted the two last contributors of evolvement and got the views for the flowchart. Then it developed a fuzzy concept evolvement flowchart as Figure 3 shows.

1) Fuzzy Concept for decision making: However, when considering the decision-making method in MCGDM (6 in Figure 2) it could observe that MCGDM untiled several customised methods based on fundamental fussy methods which evolved from Type-1 fussy method. In Type-1, it considered the membership function of the preferences (based on a mathematical model) and in the next development, Type-2 considers the membership function as a fuzzy set (based on a logical model). Then in type-2 situation, it developed the sequence of fuzzy set operations

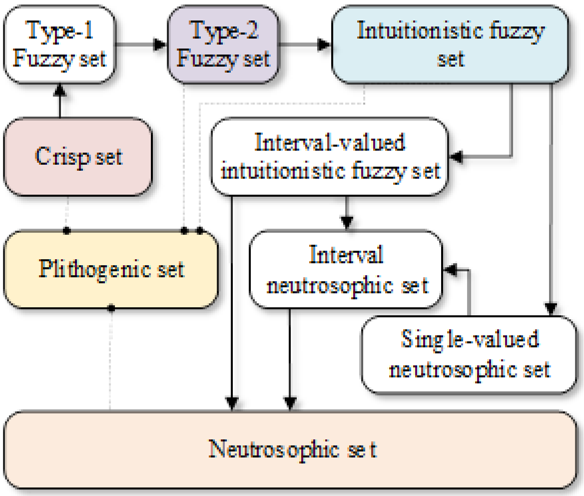


Figure 3: Extensions and relations of fuzzy concepts
Source: adopted from Alcantud (2018, p.4), Smarandache (2018) and Kaya, Çolak and Terzi (2019)

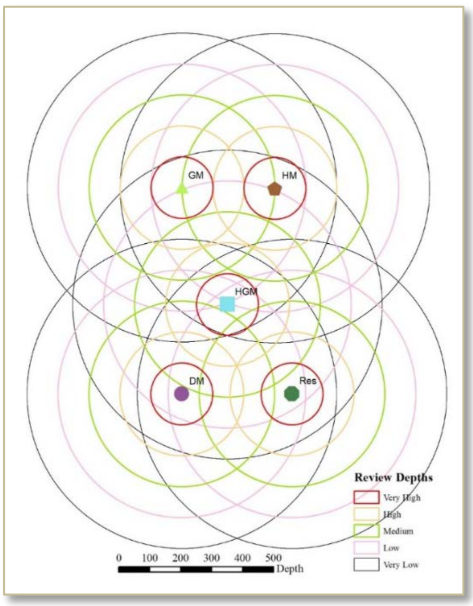
based on the individual criteria.

For example, if decision-makers think, "Learning" and "Teaching" both must be there to influence the student's "Creativity", the assigned fuzzy values of "Learning and Teaching" for a particular student need to be multiplied (fussy multiplication) to get the value for creativity. And in other ways of thinking, say either "Learning" or "Teaching" can influence "Creativity", then it must employ fuzzy summation. Further, in Type-1, "Learning" and "Teaching" have individual real values varying between 0 and 1. Type-2 is also exactly the same but due to the multiple experts, the real values become a set, and, in each row, all the criteria may not appear, i.e. some experts believe only "learning" is enough for "creativity" while others believe are both required. Such various situations are further described as soft sets and hypersoft sets.
Then when it moves to more advanced intuitionistic fussy methods, the non-membership function is also considered. The intuitionistic concept enhances the result accuracy by not only including the preferences of the experts (membership function), but also the agony of the alternatives (non-membership function). Further, the researchers have included the foresaid ***hesitant*** function to represent the uncertainty between membership and non-membership degrees. Hesitation became a base for other interest development of a fussy concept called Neutrosophic fuzzy. It can be seen as a combination of *intuitionistic* with *hesitation*, but it generalises the intuitionistic fussy set to true membership, intermittency and false–membership.
Then the concept is moved towards Plithogenic fuzzy, and the degree of appurtenance of the elements is encountered. As shown in Figure 3, the Plithogenic concept pay concern the degree of appurtenance for each and every attribute of each member. Then when considering the same example of "Learning" and "Teaching", all other methods carry out an operation based on a crisp, fuzzy, intuitionistic or neutrosophic set used to find a single value for a student. But when Plithogenic sets, it does not carry out any operation and shows each assigned attribute value separately for "Learning" and "Teaching" for a student.

2) Selection of Fuzzy logic for the present work: Then the present research has understood that the fussy logic base method (6 in Figure 2) can be customised according to not only the variable requirements but also to the level of accuracy it predicts. Hence it needed to decide the level of evaluation accuracy of the developed framework which is going to evaluate in this study. For that it mapped the present developed framework components in a scaled 2-D cartesian plane, converting the integration depths to spatial distances using GIS software. The distances between the components were calculated using the values indicated in the final framework (Figure 1). There, the values are varying from 1 – very low to 5-very high. Then when mapping those, it considers that the closeness (the integration depth) should be visualised inversely, i.e the closer objects are placed closer to each other. Hence, it recalculated the inverse of the depths using Eq. 1. The developed map with a demonstration of each component's review depths is shown in Figure 4.

$$Reveiw\ distance_{ij} = 5 - Integration\ Depth_{ij} \quad (1)$$

Where
Review distance$_{ij}$ = Integration depth distance between ith and jth components
Integration Depth$_{ij}$ = Integration depth of ith and jth components



[Note: GM: GIS Modellers, HM: Hydro Modellers, HGM: HydroGIS modellers, DM: Decision Makers, Res: Recipients]

Figure 4: Spatial Demonstration of Components' Deployment

The different coloured circles shown in Figure 4 illustrate the theoretical viewshed of each component. For example, the areas belonging to “Very High” and “High” circles of GIS modellers (GM) do not contain any other component. But the Hydro Modellers (HM) are placed on the “Medium” circle of GM. That means GMs considered the HM in medium level importance when they make their decisions in flood management. Figure 5 shows only the circles where such conditions are satisfied.

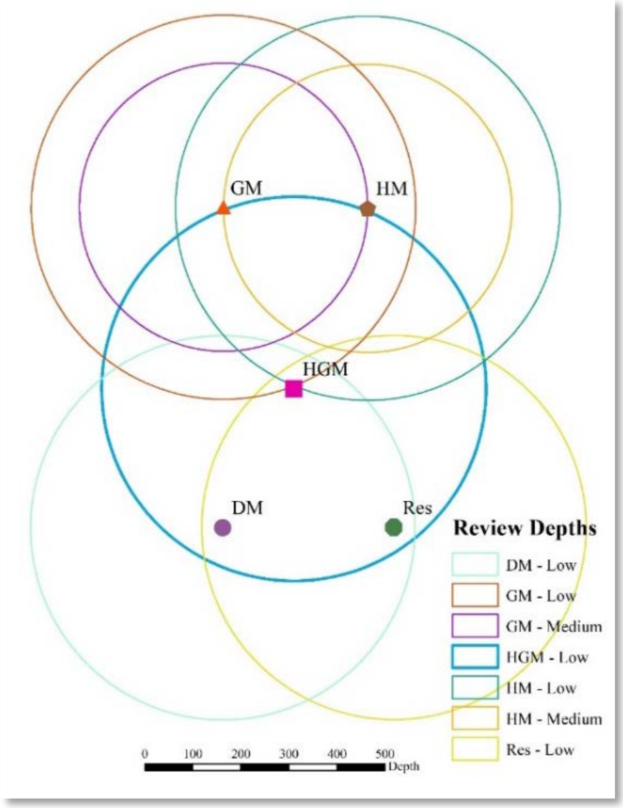


Figure 5: Overlapping of review depths

Using the extracted data shown in Figure 5, it created a 3-D map. To highlight the places where GM, HM, HGM, DM and Recipients are situated, it created tiny areas for each of them and labelled them as “very high”. This creation is based on the hypothesis that, each of them (GM, HM, HGM, DM and Recipients) are studying their subject area at a “very high” level when they decide on flood management. Based on such areas, it created Triangular irregular networks (TIN), where the heights are taken from the marked circles. The two views of TIN are shown in Figures 6 and 7.

The 3-D view shown in Figure 6 demonstrates a clear departure of one study area from others and always others falling in areas of “medium” or “low” interest levels. As well according to Figures 7 and 8, it can observe that there is a very small area with very high and very low-level review depths. As well most of the areas are covered by the “Low” while a moderate area is belonging to “Medium”.

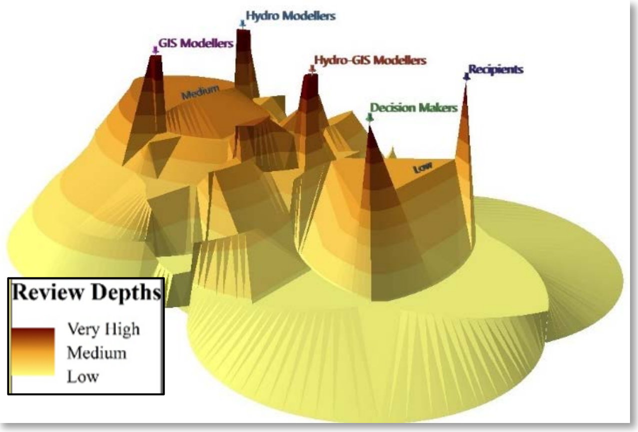


Figure 6: 3-D View of the review depths (Inversed to hights)

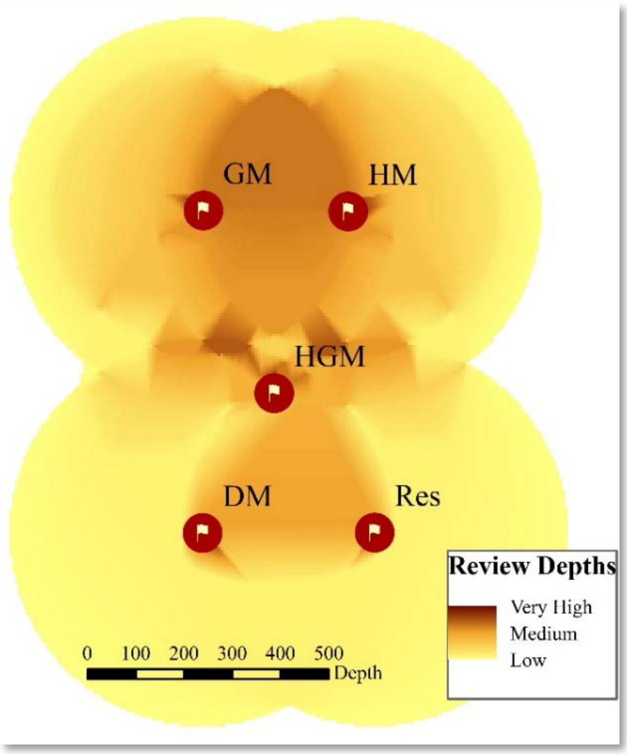


Figure 7: Cumulation of all review depths

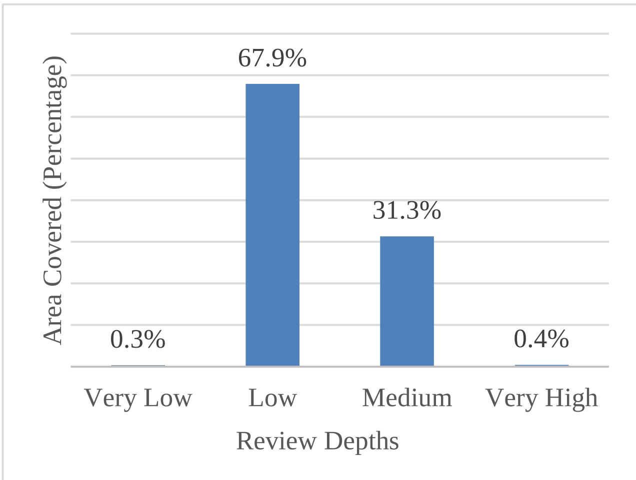


Figure 8: Comparison of review depth area distribution

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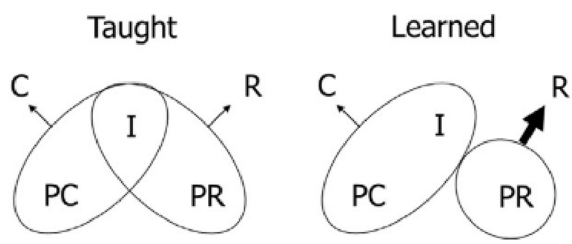
3) Attention and Attention Schema Theories

Therefore, it is more arguable to translate the above finding as, "the stakeholders in the full understanding of their own taught area but with low attention on the areas where they have not learnt". However, this hypothesis has proved, and such an attitude of the people is described using attention theory. According to the theory, when people learn new knowledge, they utilised the taught knowledge as the trusted base source and consider the new knowledge as an extension of such taught knowledge (Huang & Sherman, 2018). Due to this mentality, the individual stakeholder in the flood management process is believing the rest of the knowledge is built on its own subject area. Therefore, when commenting on such an unknown thing, there is a higher possibility to give lesser importance to *new knowledge* than own (Figure 9).



Note:
Taught: It is taught that PC and I are the reason for C and PR and I is the reason for R.
Learned: But if one has already learned that PC and I are the reason for C, and PR is still to learn, then he considers that PR is the reason to R but has no relation to I. A such belief developed according to Attention Theory.

Figure 9: Explanation of Attention theory

Source: (Huang & Sherman, 2018)

Nevertheless, in some situations, the reviewer claims that "I have a subjective experience of *new knowledge*". Then according to the Attention Schema Theory, this awareness is a piece of information, and the reviewer started to believe that he also knows the level of importance of a *new knowledge* area (Graziano, 2013, p. 29).

4) Expert Review Explanation

As an example, imagine a GIS modeller (GM) who has been in flood management for decades, and is going to comment on the importance of Decision Makers (DM). According to his experience, the DM is implementing the developed model, but the development of a such model scientifically as well as accurately is the most important and difficult work. Then according to the GM, flood management is his own work, but DM is new learning based on his work (attention theory). Further with experience, GM knows the DM is a simple implementation of the hardly developed model which appears everywhere (Attention Schema Theory). With this attitude of the GM, there is a high chance of commenting the DM integration as a less important requirement in urban flood management than GIS modelling (Figure 10).

Hence due to this Attention and Attention Schema Theory applicability, it can predict that the professional comments to be taken to the framework evaluation, will be having most of the time positive attitude towards the other knowledge areas, but rarely expect negative feedback. Then, it can argue that fuzzy values of the expert preferences are justifiable to have only the membership function where it appears in the Type-1 fuzzy concept.

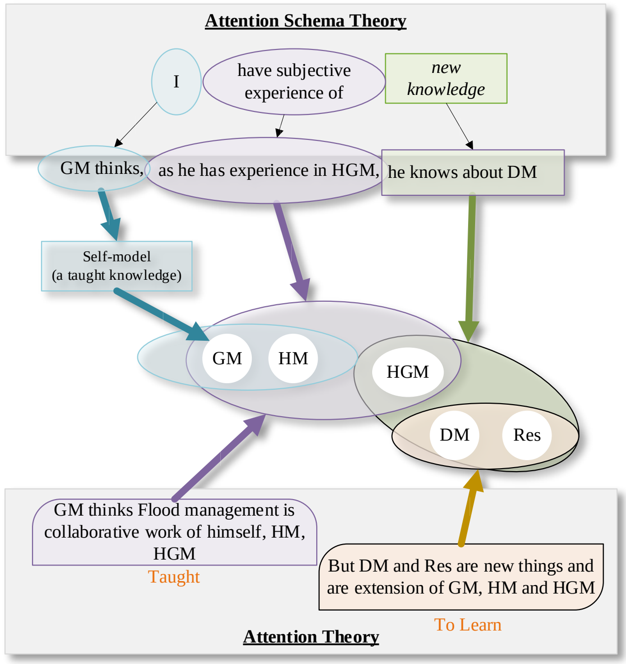


Figure 10: Attention and Attention Schema Theory Application in HydroGIS Model Development Framework

II. APPLICATION OF MCGDM

A) Evaluation Criteria and Questionnaire Development

The developed HydroGIS framework was required to be reviewed to find the (1) adequacy for the utilisation, (2) satisfaction with the representativeness, and (3) need & use with the merits & demerits. Then those become the main evaluating points and set the questionnaire's questions aligned with those. The questionnaire was developed following a repetitive development method (Pradeep & Wijesekara, 2019). The details of the main review points, sub-review point, question/statement and answer structure, of the questionnaire, are shown in Table 1. The final version of the questionnaire was developed as an online google form. The questionnaire was electronically distributed among over 5000 potential experts in Hydrology, GIS, HydroGIS modelling, Computing and Decision-Making. It followed the Respond Driven Sampling method and collected 70 responses. As the equal percentage of experts in each expert area, carrying substantial experiences and education qualifications, it is considered that the sample is representative.

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Table 1: Evaluation Criteria and Question Mapping

Main review point	Sub review point	The Question/statement	Answer Structure
Adequacy	1. On Components	i.Do you feel all the required components are included in the framework?	1-3 Likert Scale or Comment
	2. For tool development	ii.Do you feel all the integrations (not the percentages) in the developed framework are appropriate for developing better tools?	1-3 Likert Scale or Comment
Satisfaction	3. Over present arraignment	iii.The percentage of integration found through research (xx%) is accurate (for each separately)	1-7 Likert Scale
	4. On degree of integration	iv.This integration is highly required (for each separately)	1-7 Likert Scale
		v.This is a very important integration	1-7 Likert Scale
Views on framework	5. Priority order of integration	vi.Mark the order of favour when considering all the 5 integrations	1-5 priority order
	6. Over present arraignment	vii.If you think the percentage found through research (xx%) should be different, then what should it be? (for each separately)	Open-ended
	7. Of completeness	viii.Please provide your views / opinions / ideas / critics on this integration (for each separately)	Open-ended
	8. Merits and demerits	ix.Describe any merits or/and demerits of the framework. Please give your suggestions too	Open-ended
	9. Need and Use	x.Please provide your views / opinions / ideas / critics on each integration	Open-ended

B) Mapping MCGDM steps

MCGDM is utilised to find the preference order of the Likert-scale questions and statements only. All other open questions were analysed using thematic analysis. Then the MCGDM which is shown in Figure 11 is employed for each sub-review point and data were accumulated to get the view for the main review point.

1) Experts: The present work selected 68 reviews of the participants (hereafter experts) after excluding the unrealistic answers.

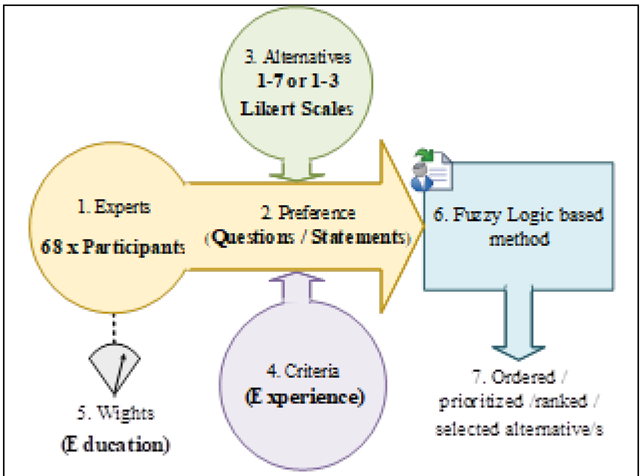

Figure 11: Map of present work activities to MCGDM activities

2) Alternatives and Preferences: Each expert selected one of the alternatives for each question/statement (sub-review point) as the preference. For example, consider the statement "Percentage of integration found through research is accurate". Then the expert has 7 alternatives to be selected, (1) Completely Agree, (2) Mostly Agree, (3) Slightly Agree, (4) Undecided, (5) Slightly Disagree, (6) Mostly Disagree, and Completely Disagree (7).

3) Criteria and Weight: Then each preference needs to be evaluated under the criteria in the MCGDM process. However, when considering the present scenario, the expert's preference decision depends on the particular person's knowledge. However, the knowledge cannot be taken directly as well as for the present work, the person should be aware of multiple subject areas thoroughly and equally. However, through the data set, it found that majority of the experts are having experience in non-expert areas at different levels, while the education is also above bachelor's level. Then it is important to identify the criteria which affect the decision-making. Hence when considering the previous studies (Dewey, 1986; Fuller et al., 2017; Klein, 1999; Rosenberger, 2020), education and experience there are influence decision-making. Specially, it has been realised that in field decision-making processes like medicine and engineering, education cannot be replaced with experience as in-depth learning from education is important in decision making. Therefore, the present work considers that both education and experience govern the accurate decision in flood management too. Hence "Both/And – (equally important and must)" situation exists in the education and experience evaluation. Therefore, to weight the expert, it utilised the expert's education and experience utilised as a decision-making criterion for the MCGDM process. Hence, the individual years of experience are categorised into a fuzzy value using Table 2 and average experience is taken for all areas which interested in the present work (Table 3).

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Table 2: Score of the Experience Period

Assigned fuzzy value for experience (ex_n)						
> 20 years	15 to 20	10 to 15	5 to 10	1 to 5	< 1 year	No Exp
1.00	0.83	0.67	0.50	0.33	0.17	0.00

Table 3: Final weight of Experience

Experience in	**The assigned score for experience**
GIS	ex_1
Hydrology	ex_2
Land management	ex_3
Town and country planning	ex_4
Public admin	ex_5
Flood related decision making	ex_6
Software development	ex_7
Data handling/ analysing	ex_8
Construction	ex_9
Pub water management	ex_{10}
Pvt water management	ex_{11}
Other	ex_{12}
Weight of the Experience (E_{ex})= Average (ex_1 to ex_{12}) where $ex_n > 0$	

In the same way, it scores the education of the expert as shown in Table 4.

Table 4: Score of the Highest Education Qualification

Assigned fuzzy value for Weight the Education (E_{ed})								
Snr Prof	Prof	PhD	Mphil	Prof	MSc	PG	BSc	Sec. Edu
1	0.875	0.75	0.625	0.625	0.5	0.375	0.25	0.125

4) Fuzzy Logic Based Method: To prioritise the preferences, it is required to find a weighted list. Then instead of weighting the preference, each expert was weighted using Eq. 2.

$$\boldsymbol{E_w = (E_{ex} \times E_{ed})} \quad (2)$$

Where

E_w : Expert’s Weight

E_{ex}: Weight of the Experiences

E_{ed}: Weight of the Education

MCGDM was employed to evaluate 1 to 6 sub-review points (See 2nd column of Table 1). The first 4 sub-review points had 5 questions/statements and it asked the preference on the Likert scale. Then those preferences are prioritised according to the professional categories, following the flowchart shown in Figure 12. The values received to rank each preference were accumulated according to the main review point and computed in two priority lists for the main two review points, (1) Adequacy (Table 5) and (2) Satisfaction (Table 6).

The 5th and 6th sub-review point questions asked for (1) Mark the priority being given to integrations in framework components according to the preferences and (2) insert the preferred integration percentages for each % value shown in Figure 1. To find the different priorities assigned to the different integrations it utilised Eq.3. Results are shown in Table 7.

$$WAI_i = \frac{\sum P_i \times E_w}{\sum E_w} \quad (3)$$

Whare

WPI_i = Weighted priority order number for i^{th} integration

P_i = Expert Preferred priority number for the integration which varies from 1 (minimum) -5 (maximum)

E_w = : Expert’s Weight (see Eq.. 2)

For find the experts preferred integration percentages for it utilised the Eq.4. Results are shown in Table 8.

$$WPI_i = \frac{\sum A_i \times E_w}{\sum E_w} \quad (4)$$

Whare

WAI_i = Weighted percentage for i^{th} integration

A_i = Expert Preferred Percentages for the individual integration

E_w = : Expert’s Weight (see Eq.. 2)

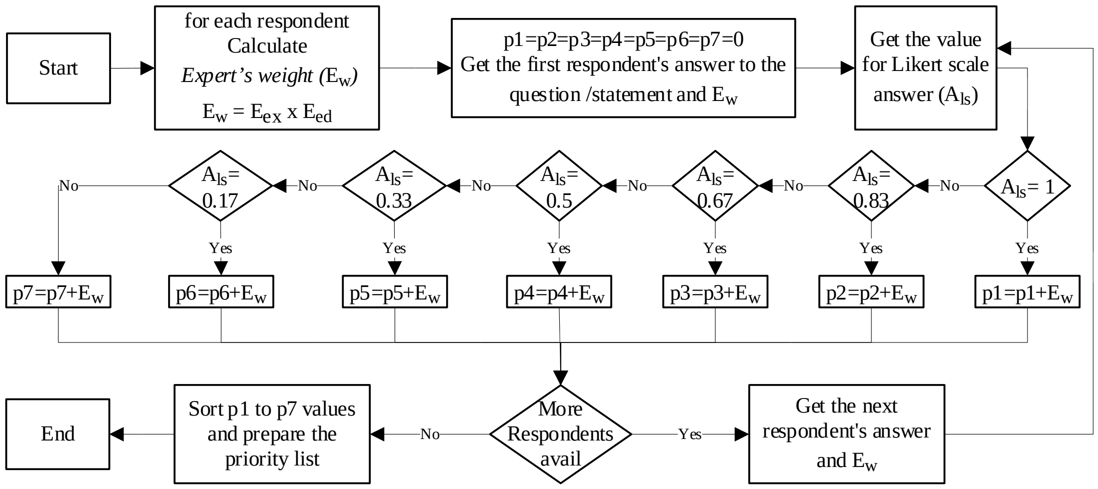

Figure 12: Flowchart of Priority order calculation

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C. Simple Calculation

The same calculation process was applied to the same dataset without utilising the fuzzy weight on the experts and preferences (same MCGDM steps without using the fuzzy criteria). Table 9 to 12 shows the simple calculation results which are consecutively the same as Table 5 to 8.

Table 5: Prioritised List of Preference for Adequacy of Framework - MCGDM Calculation

Option	Adequacy				Final Adequacy
	DM	GM	HGM	HM	
Completely Agree	1.25	1.65	7.12	0.34	10.37
Mostly Agree	1.38	2.34	0.68	2.73	7.13
Slightly Agree	0.26	0.66	1.76	0.06	2.75
Undecided	0.00	0.33	0.21	0.00	0.54
Slightly Disagree	0.00	0.00	0.00	2.04	2.04
Mostly Disagree	0.00	0.05	0.00	0.00	0.05
Completely Disagree	0.00	0.00	0.00	0.19	0.19

Note:
DM: Decision -makers GM: GIS Modellers
HGM: HydroGIS / SW Modellers HM: Hydro Modellers

Table 6: Prioritised List of Preference for Satisfaction of Framework - MCGDM Calculation

Option	Satisfaction				
	DM	GM	HGM	HM	Overall satisfaction
Completely Agree	7.17	17.97	26.64	14.41	66.19
Mostly Agree	7.98	11.03	29.25	7.51	55.77
Slightly Agree	3.40	4.73	8.09	2.71	18.93
Undecided	2.01	6.00	2.44	5.49	15.94
Slightly Disagree	1.65	1.89	1.51	2.21	7.26
Mostly Disagree	0.52	3.00	5.33	7.90	16.75
Completely Disagree	0.00	0.05	0.08	0.00	0.13

Note:
DM: Decision -makers GM: GIS Modellers
HGM: HydroGIS / SW Modellers HM: Hydro Modellers

Table 7: Preferred Priority Order Assigned to Different Integrations by Experts in Different Professional Categories – MCGDM Calculation

Professional Category	The priority order given by the experts				
	Hydro Modelers and GIS Modelers	Hydro and GIS Modelers and HydroGIS-Modelers	HydroGIS-Modelers and Decision-Makers	HydroGIS-Modeler and Recipients	Decision-Makers and Recipients
Decision Maker	4.01	3.03	3.39	3.29	4.39
GIS Modeller	4.47	4.43	4.24	3.59	3.83
Hydro-GIS Modellers	4.54	4.34	4.11	3.73	4.23
Hydro Modellers	3.47	3.65	3.94	4.07	3.97
All participations	4.22	4.04	4.01	3.72	4.10

Table 8: Preferred Integration Depths of the Experts in Different Professional Categories - MCGDM Calculation

Professional Category	The expert thinking depths of the integration should be (%)				
	Hydro Modelers and GIS Modelers (26%)	Hydro and GIS Modelers and HydroGIS-Modelers (12%)	HydroGIS-Modelers and Decision-Makers (23%)	HydroGIS-Modeler and Recipients (19%)	Decision-Makers and Recipients (19%)
Decision Maker	13.41	13.54	10.29	25.41	37.35
GIS Modeller	45.38	13.36	11.70	10.30	19.27
Hydro-GIS Modellers	30.42	17.48	19.57	16.37	16.15
Hydro Modellers	22.91	19.07	20.29	23.88	13.85
All participations	29.13	16.49	16.76	18.51	19.11

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Table 9: Prioritised List of Preference for Adequacy of Framework – Simple Calculation

Option	Adequacy				Final Adequacy
	DM	GM	HGM	HM	
Completely Agree	11.00	12.00	21.00	5.00	49.00
Mostly Agree	17.00	11.00	7.00	23.00	58.00
Slightly Agree	3.00	5.00	3.00	4.00	15.00
Undecided	0.00	2.00	1.00	0.00	3.00
Slightly Disagree	0.00	0.00	0.00	3.00	3.00
Mostly Disagree	0.00	1.00	0.00	0.00	1.00
Completely Disagree	0.00	0.00	0.00	1.00	1.00

Table 10: Prioritised List of Preference for Satisfaction of Framework - Simple Calculation

Option	Satisfaction				
	DM	GM	DM	GM	Overall satisfaction
Completely Agree	76.00	102.00	108.00	75.00	361.00
Mostly Agree	73.00	75.00	76.00	91.00	315.00
Slightly Agree	34.00	26.00	29.00	48.00	137.00
Undecided	28.00	34.00	13.00	25.00	100.00
Slightly Disagree	22.00	13.00	5.00	13.00	53.00
Mostly Disagree	7.00	19.00	8.00	18.00	52.00
Completely Disagree	0.00	1.00	1.00	0.00	2.00

Table 11: Preferred Priority Order Assigned to Different Integrations by Experts in Different Professional Categories – Simple Calculation

Professional Category	The priority order given by the experts				
	Hydro Modelers and GIS Modelers	Hydro and GIS Modelers and HydroGIS-Modelers	Hydro Modelers and GIS Modelers	HydroGIS-Modeler and Recipients	Hydro Modelers and GIS Modelers
Decision Maker	4.06	3.44	3.44	3.31	4.19
GIS Modeller	4.56	4.39	4.11	3.39	3.61
Hydro-GIS Modellers	4.50	4.25	4.19	3.69	4.44
Hydro Modellers	4.39	4.11	3.72	3.72	3.67
All participations	4.38	4.06	3.87	3.53	3.96

Table 12: Preferred Integration Depths of the Experts in Different Professional Categories - Simple Calculation

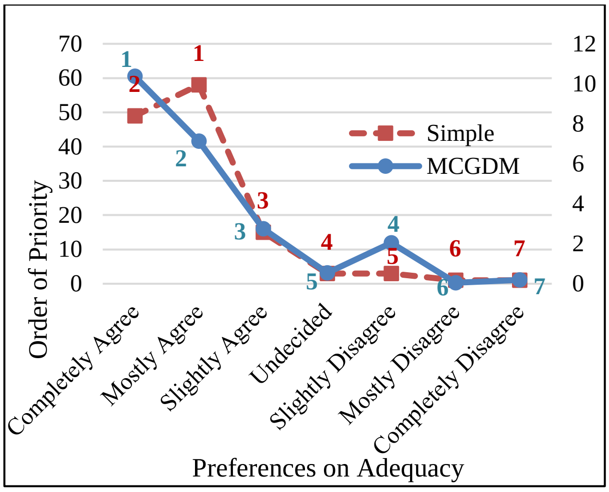
Expert	**The expert thinking depths of the integration type (%)**				
	Hydro Modelers and GIS Modelers (26%)	Hydro and GIS Modelers and HydroGIS-Modelers (12%)	HydroGIS-Modelers and Decision-Makers (23%)	HydroGIS-Modeler and Recipients (19%)	Decision-Makers and Recipients (19%)
Decision Maker	18.60	18.95	12.83	19.52	30.10
GIS Modeller	35.91	14.51	14.76	13.72	21.10
Hydro-GIS Modellers	22.39	11.49	26.60	20.89	18.62
Hydro Modellers	30.88	16.56	18.12	23.08	11.36
All participations	27.37	15.63	17.65	19.41	19.93

D. Comparison of MCGDM and Simple calculation outputs

The comparisons of MCGDM calculation outputs between with-fuzzy weights and without-fuzzy (simple) are shown in Figures 13 to 15.

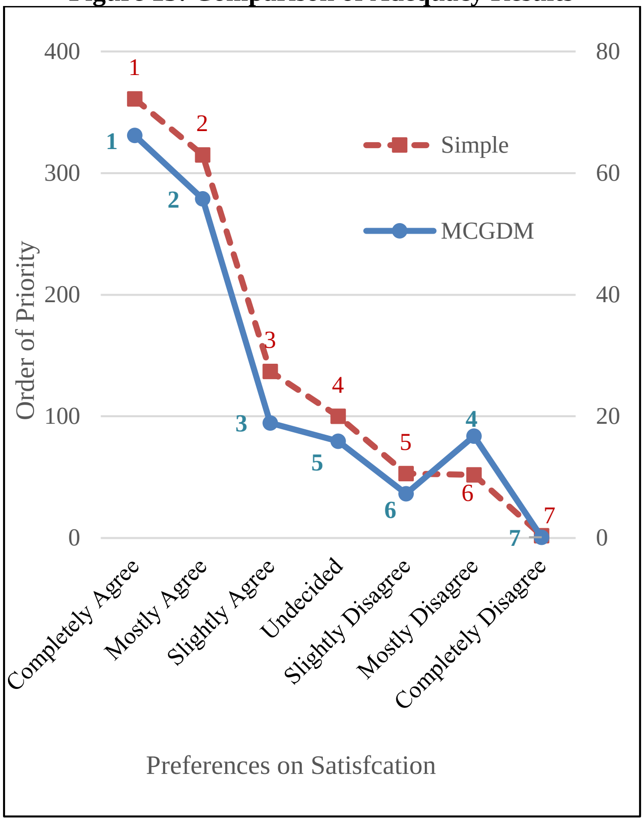
When considering the MCGDM result of the priority list of the adequacy preferences on the framework, it shows that the "Completely Agree" preference wins but in simple calculation the "Mostly Agree" wins. As well, the preference for satisfaction also shows priority order differences in "Undecided, Slightly Disagree and Mostly Disagree" alternatives.

Apart from that, when considering the differences between results of MCGDM and non-weighted methods, the priority calculated for each integration type is the same (Figure 15), As well when considering the preferred integration depths for each integration type (Figure 16), they differ from each other only by 0.82% (min) – 1.72 %(max) only. Hence, there is not any significance in the results for both analyses.



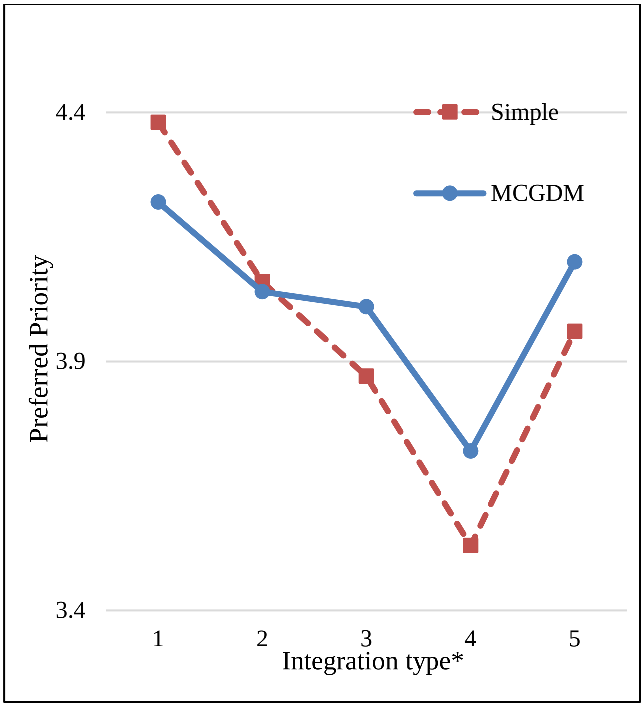
Note: Numbers on the nodes show the priority

Figure 13: Comparison of Adequacy Results



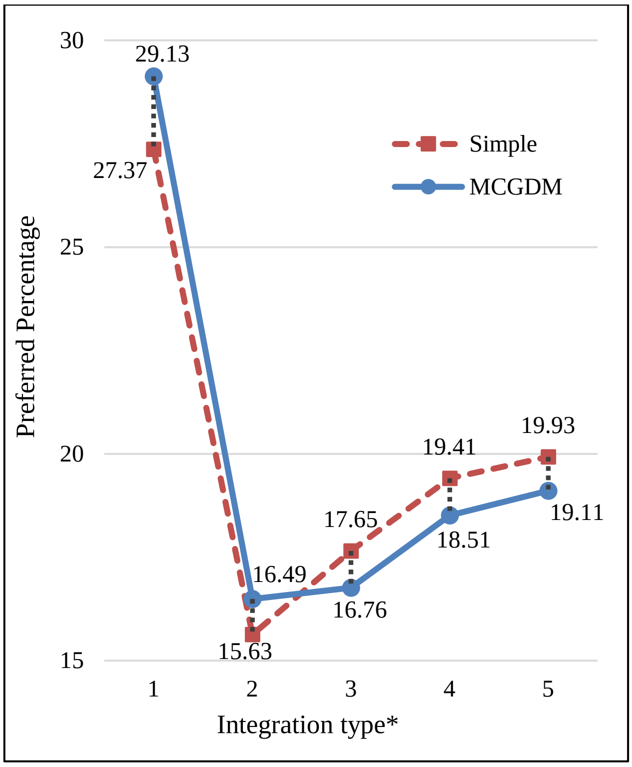
Note: Numbers on the nodes show the priority number

Figure 14: Comparison of Satisfaction Results



Note: * Integration type numbers denote.
1: Hydro Modelers and GIS Modelers
2: Hydro and GIS Modelers and HydroGIS-Modelers
3: HydroGIS-Modelers and Decision-Makers
4: HydroGIS-Modeler and Recipients
5: Decision-Makers and Recipients

Figure 15: Comparison of Priority Results



Note: *See Figure 15 note for Integration type descriptions

Figure 16: Comparison of Preferred Percentages for each Integration

III. RESULT AND DISCUSSION

The present work attempted to select a suitable evaluation method for verifying the HydroGIS model development framework due to the intended framework demonstrating transdisciplinary stakeholders and activities to the software professionals to understand and construct sustainable urban flood management tools. Speciality in this evaluation is, that it required the reviews of not only the software professionals but also the other experts in the related disciplines. Due to the symmetrical methods distorting the real emotions of the reviews, the present work selected the MCGDM method which is in the MCDA family as the previous works proved the applicability of such in flood-related research. As the methodology has been practised in different approaches it summarised and construct a generalized MCGDM process map (Figure 2).

As the MCGDM heavily employed the Fuzzy concept in the analysis, the present work developed a verified map of different fuzzy logics and their relations (Figure 3).

The fuzzy logic types are employed based on the expected accuracy resolution, then, the present work analysed the accuracy requirement through 2D and 3D spatial analysis and the attention and attention schema theory. Finally, it selected Type 1 fuzzy concept as sufficient for the work.

The application of MCGDM is demonstrated with HydroGIS framework evaluation. for that, expert reviews were collected via a systematically developed questionnaire based on the main three review points, accuracy, satisfaction and Views on the framework. The data were analysed using the fuzzy weighted MCGDM method and simple method without using the fuzzy criteria. The comparison shows that MCGDM effectively demonstrates the qualitative preference variations among the population than the simple method. However, when the questions are based on the quantitative value expressions, Fuzzy based MCGDM and simple method result differences are less significant.

When considering the HydroGIS framework evaluation, it shows that experts mostly agreed with the adequacy of the framework to their work and completely agree with the satisfaction of the components in the framework.

IV. CONCLUSION

The present work is able to successfully modify and employ the MCGDM method for HydroGIS framework verification satisfactorily as calculations result substantially illustrate the real emotions of experts.

Even though there is a more complex fuzzy concept availed, the researchers should pay attention to selecting suitable fuzzy concepts systematically. The present work demonstrates how to employ spatial analysis and attention theory for systematic selection.

Finally, the developed HydroGIS model development framework is accepted by the experts as a framework which adequately develops for its own utilisation and satisfactorily represents the real world.

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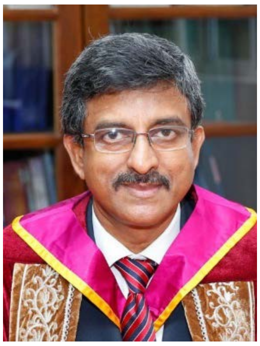

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