A Comparative Study on Flood Vulnerability Mapping Through Morphometric Indices with MCDM Techniques

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ABSTRACT: Climatic change is the major issue threatening the lives in the current phases. This dynamic alteration in climate has led to a typical change in the rainfall pattern resulting in flood condition, which makes devastating damages to the natural and cultural environment. So, it is essential to demarcate the vulnerable zones to reduce the losses caused from the disastrous event. Accordingly, the Manimala watershed is selected which is prone to frequent flood events in the recent times. The present study is focusing on the sub-watershed based flood vulnerability mapping using the morphometric factors through traditional methods like Compound Factor (CF) analysis, Multi-Criteria Decision Making (MCDM) method of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and VlseKriterijuska OptimizacijaI Komoromisno Resenje (VIKOR). Thus, to understand the watershed characteristics and hydrological behaviors, 10 significant factors were selected based on the interrelationship and influencing criteria regarding to flood. Each factor is weighted and ranked based on degree of influence towards the possibility of flood. Thus, for evaluating the suitable technique for precise assessment, the non-parametric correlation tests of Kendall Tau Correlation Coefficient Test (KCCT) are attempted and out of the three techniques CF shows acceptable and significant result for the study region. Hence the results of CF, identifies that the SW-7, SW-8 and SW-9 is exhibiting very high flood vulnerability and needs immediate implementation of conservation measure and flood management strategies.

1. Introduction

Floods are the most common and the deadliest of the world's environmental threats, it is a high flow of water which overtops either the natural or the artificial banks of a river. It is primarily a hydrological phenomenon and its occurrence is generally the result of meteorological actions. The growing trend in the occurrence of flood events is mainly due to the ongoing changes in climate and land use caused by human activities (Hirabayashi et al. 2013; Sofia et al. 2017). In addition, anthropogenic effects also restrict the natural capacity of basins to maintain and transform, which can contribute to increased surface runoff or processes of erosion (Fohrer et al. 2001; Costache et al. 2015). Floods impact the ecosystem and society by destroying habitats, affecting lives, damaging infrastructure, etc. Hydrologically, a flood occurs when an unusually extreme or prolonged water-input event is encountered in the drainage basin and the resultant streamflow rate exceeds the capacity of the channel (Dingman, 2008). Morphometric analyses have aided the description of processes such as flooding, erosion and mass movement (Baumgardner, 1987). The assessment of basin morphometry was more precise, rapid and cost-effective with the advent of the Geographic Information System (GIS), high-resolution digital elevation models (DEMs), and remote-sensing techniques (Bertolo 2000; Ahmed et al. 2010). In the Western Ghats catchments, heavy rainfall during the year of 2018 in Kerala caused flood including Pathanamthitta, Alappuzha, Kottayam, Idukki, Ernakulam, Thrissur and Wayanad districts. Built-up areas in the downstream of the basins of Achankovil, Pamba, Meenachal, Moovattupuzha, Periyar, Chalakudi and the study region Manimala, were inundated by the floodwaters, disrupting the life of casualty, and warranting relocation in safe shelters. In the present study, an attempt is made to delineate the catchment boundary and extraction of drainage networks from ALOS-PALSAR DEM (Venkatesh et al., 2020) for the Manimala watershed. Evaluating and prioritizing morphometric factors with respect to floods has been derived using CF, TOPSIS and VIKOR to understand the hydrological behavior and the outcome is validated by KTCCT (Non parametric correlation test) for identifying significant method for prioritizing sub-watershed based on flood vulnerability in the Manimala watershed.

2. Study Region

The Manimala watershed covers an area of 788.9 sq.km. spreading across the Kottayam, Pathanamthitta and Alapuzha districts. Manimala watershed has a length of 44.45 km and Perimeter of 246.1 km and it lies between the North latitudes of 9º 21' 10" and 9º 30' 15" and the East longitudes 76º 54' 6" and 76º 34' 51". In general, the area covered by the basin experiences tropical climate. Most of the rainfall of the Manimala watershed is contributed by the South-west monsoon from June to September and North-east monsoon from November and December. The watershed is segregated into 9 sub-watersheds from SW-1 to SW-9 as shown in figure 1, which characterized predominantly by dendritic, sub-dendritic, trellis or rectangular pattern. Hornblende gneiss, granite gneiss, granite and calc granulite are the main rock types present in the North-east region of the watershed. Loamy, gravelly loam, clay and gravelly clay are the dominant soil types. Steep valleys, plateau, isolated hillocks, escarpments and high hills are the outstanding geomorphological features. In general, a diverse land use pattern, characterized by rubber and tea plantations, cardamom forests, coffee, mixed crops etc. with settlements and urban areas are observed.

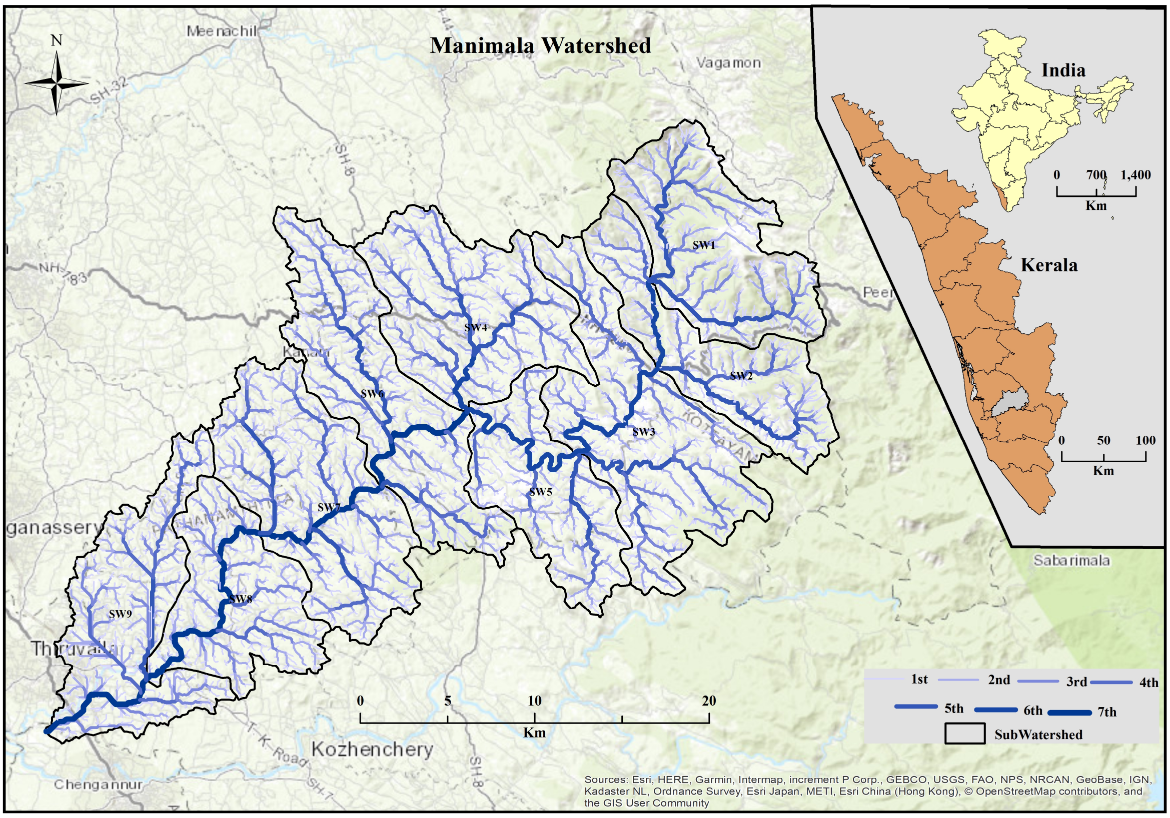

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Figure 1: Spatial representation of Manimala watershed Kerala, south India

3. Methodology

The framework of the study is to compare the individual (Compound Factor-CF) and MCDM (Technique of Order Preference Similarity to the Ideal Solution-TOPSIS, VIšekriterijumsko Kompromisno Rangiranje-VIKOR) technique for prioritizing the watershed regards to flood vulnerability and the ranking correlation between these techniques are validated with the Kendall Tau Coefficient Correlation Test. Around 10 morphometric factors are selected for prioritization such as bifurcation ratio (R_b), mean stream length (L_{sm}), stream frequency (F_s), drainage density (D_d), drainage texture (D_t), form factor (F_f), infiltration ratio (I_f), sinuosity (S), relief ratio (R_h), length of overland flow (L_g). These factors are calculated through defined formula introduced by pioneer researchers (Horton, 1932, 1945; Schumm, 1956; Gregory & Walling, 1973). The numerical values of each factors determine the degree of influencing towards flood possibility. Each morphometric factor is weighted and ranked through the CF, TOPSIS and VIKOR techniques using equation (1, 5, 7), in which the best methods are selected by analysing the correlation coefficient values (KTCCT) using equation 10.

3.1. Compound Factor (CF)

Compound factor analysis is a traditional knowledge-based model for ranking the alternatives (Todorovski & Džeroski, 2006). This model evaluates the ranking of each alternatives by converting qualitative values into quantitative values with the scientific understanding of selected alternatives (morphometric factors) (Ameri et al. 2018; Nitheshnirmal et al., 2019). The equation (1) is used for assigning the CF values each alternative.

$$CF = \frac{1}{n}\sum_{i=1}^{n} R \quad i = 1, 2, ...m \quad \text{where R is rank, and n is number of alternatives} \tag{1}$$

3.1 TOPSIS-(Technique of Order Preference Similarity to the Ideal Solution)

TOPSIS technique was initially developed by Hwang and Yoon (1981) to select the criteria by measuring Euclidean distance between each alternative. The working principle of TOPSIS is measuring the Euclidean distance of individual alternative from ideal best (Positive Ideal Solution) and ideal worst (Negative Ideal Solution) (Hwang and Yoon, 1981). The distance is measured as closeness coeffect value (P_i), it represents a minimum distance to ideal best and maximum distance from ideal worst (Kannan, 2009). The alternatives (morphometric factors) selected for the study were prioritized with the TOPSIS technique with the following steps.

Vector normalization of each $\overline{X}_{ij}$ of decision matrix and weighted normalized value V_{ij} of each X_{ij} elements is computed using eq (2)

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^{2}}} \quad \& \quad V_{ij} = \overline{X}_{ij} \times W_{ij} \tag{2}$$

Determination of ideal best A^+ (Positive ideal solution) and ideal worst A^- (Negative ideal solution) value through eq (3)

$$A^{+} = \left\{ \left(\max V_{ij} \mid j \in J \right), \left(\min V_{ij} \mid j \in J' \right) i = 1, 2, ...m \right\} = \left\{ V_1^{+}, V_2^{+}, ...V_j^{+} ....., V_n^{+} \right\}$$

$$A^{-} = \left\{ \left(\min V_{ij} \mid j \in J \right), \left(\max V_{ij} \mid j \in J' \right) i = 1, 2, ...m \right\} = \left\{ V_1^{-}, V_2^{-}, ...V_j^{-} ....., V_n^{-} \right\} \tag{3}$$

Calculation of Euclidean distance from ideal best (A^+) and ideal worst (A^-) using eq (4)

$$S_i^+ = \sqrt{\sum_{j=1}^{m}\left(V_{ij} - V_j^+\right)^2}\ i = 1,2,....,n\ \&\ S_i^+ = \sqrt{\sum_{j=1}^{m}\left(V_{ij} - V_j^-\right)^2}\ i = 1,2,....,n \tag{4}$$

Finally, Closeness coefficient/Performance score (P_i) of each element is evaluated using eq (5)

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}\ i = 1,2,....,n \tag{5}$$

3.2. VIKOR-(VIšekriterijumsko Kompromisno Rangiranje)

VIKOR is unique ranking methods in MCDM, introduced by (Opricovic, 1998) to overcome the problem of inconsistent criteria in a complex system. The weights and rank of each alternatives are assigned by measure of closeness to ideal alternatives (Opricovic & Tzeng, 2004). In this study, VIKOR helps to assign the weightage-based raking with the index values (Q_i) to prioritizing the watershed regards to flood risk. The following steps helps to compute the VIKOR index value for each alternative (morphometric factors).

Using the eq (6), Utility measure (S_i) and individual regret measure (R_i) of each element (X_{ij}) is computed

$$S_i = \sum_{j=1}^{m}\left(W_j * \frac{X_i^+ - X_{ij}}{X_i^+ - X_i^-}\right)\ \&\ R_i = \underset{j}{Max}\left(W_j * \frac{X_i^+ - X_{ij}}{X_i^+ - X_i^-}\right) \tag{6}$$

Calculating of VIKOR index value (Q_i) (El-Santawy, 2012) through eq (7)

$$Q_i = v\left(\frac{S_i - S^*}{S^- - S^*}\right) + (1 - v)\left(\frac{R_i - R^*}{R^- - R^*}\right) \tag{7}$$

Where $S^* = \min_i S_i, S^- = \max_i S_i, R^* = \min_i R_i, R^- = \max_i R_i$ and "v" is maximum value of utility (usually $v = 0.5$, it ranges from 0 to 1) (Opricovic, 1998).

In VIKOR, compromise solution is proposed (Opricovic & Tzeng, 2004, 2007) to check two condition such as

C_1-Acceptable advantage: $Q\left(A^2\right) - Q\left(A^1\right) \geq \left(\frac{1}{j-1}\right)$, j is number of alternatives (8)

C_2- Acceptable advantage in decision making: Alternatives A^1 should be best ranked 1 either in S_i or/ R_i, If the condition of C_2 is not satisfy, then the alternatives solutions such as ranking of alternatives A^1, A^2,…… A^m should be follows the eq (9) (Opricovic & Tzeng, 2007)

$$A^m - Q\left(A_1\right) < \left(\frac{1}{j-1}\right) \tag{9}$$

3.4. Validation Model

Nonparametric correlation tests of Kendall Tau Coefficient Correlation Test (KTCCT) "τ" is, computed using the formula eq (10), used to compare the tradition ranking method (CF) and MCDM (TOPSIS & VIKOR) methods to validate statistical dependence (Szmidt & Kacprzyk, 2011; Chitsaz & Banihabib, 2015).

$$\tau = \frac{C - D}{\frac{n(n-1)}{2}} \quad (10)$$

Where C & D are values of concordant and discordant pair and n is the number of criteria

4. Result

4.1. Linear Aspect

Bifurcation ratio (R_b) refers to the relation of total number of streams in the existing stream order with the total number of streams in the successive stream order. It is necessary to understand the bifurcation of the streams in terms of mapping flood vulnerability. The results of R_b shows that the values range from 3.75 and 4.20, respectively. Those values are categorised in three classes as high medium and low. The high category is only marked in the SW-8, meanwhile the SW-1, 3 and 9 come under medium category as shown in figure 2. Mean stream length (L_{sm}) is equally important like R_b values as it shows the sum of the mean length of stream in specific stream order and its values ranges from 2.5 to 3.5 (Table 1). The maximum L_{sm} values is marked in SW-3, SW-4 and SW-8.

4.2. Areal Aspect

Stream frequency (F_s) refers to the attributes of the stream and underlying lithology. The values of F_s are between 6.60 and 6.80, the maximum value is found in SW-2, SW-4 and SW-7 (Figure 2). Drainage density (D_d) is indicating the infiltration rate and underlying geologic structure, its values are marked between 2.70 and 3, the maximum values is found in SW-8 and SW-9. Drainage texture (D_t) indicates the ratio of texture in the basin where its values found between 8.75 to 11.5 as displayed in table 1 and the maximum D_t values is seen in SW-4 and SW-7. Form factor (F_f) refers to the shape of the drainage basin where it is showing maximum values in SW-2, SW-5 and SW-8. Infiltration ratio (I_f) is a significant morphometric parameter for flood as it denotes the proportion of infiltration and its values are highly concentrated in SW-9. Sinuosity (S) is also a key parameter which impact the flood condition and its maximum value of 0.75 is found in SW-8.

4.3 Relief Aspect

Relief ratio (R_h) represents the degree of slope gradient and the topography which is significant for flood mapping. These values are found between 14 to 26. The highest values are marked in the SW-1 and the moderate values is marked in SW-3, SW-4 and SW-5. Length of overland flow (L_g) plays a vital role in flood as it characterises both the hydrological and physiographic behaviour of the basin. The maximum and minimum values range between 0.15 and 0.17 respectively. Whereas maximum value is noted in the SW-1 and SW-3, minimum values in SW-8 and SW-9 respectively and shown in figure 2.

Table 1: Describes about values of morphometric factors utilised for the study

Name	R_b	L_{sm}	F_s	D_d	D_t	F_f	I_f	S	R_h	L_g
SW1	3.98	2.48	6.66	2.73	11.78	0.32	18.21	0.49	79.74	0.18
SW2	3.75	3.42	7.27	2.66	10.09	0.33	19.31	0.77	62.23	0.19
SW3	4.20	4.25	6.87	2.71	10.74	0.30	18.64	0.59	25.58	0.18
SW4	3.54	2.01	7.15	2.82	13.73	0.31	20.16	0.58	20.49	0.18
SW5	3.71	3.80	6.85	2.69	10.18	0.33	18.38	0.42	26.33	0.19
SW6	3.61	3.34	6.59	2.82	10.00	0.31	18.57	0.66	11.79	0.18
SW7	3.73	3.27	7.28	2.94	14.70	0.31	21.42	0.50	14.87	0.17
SW8	4.54	4.11	6.70	3.15	10.19	0.32	21.11	1.06	12.52	0.16
SW9	3.93	3.48	6.83	3.30	8.71	0.32	22.51	0.48	6.54	0.15

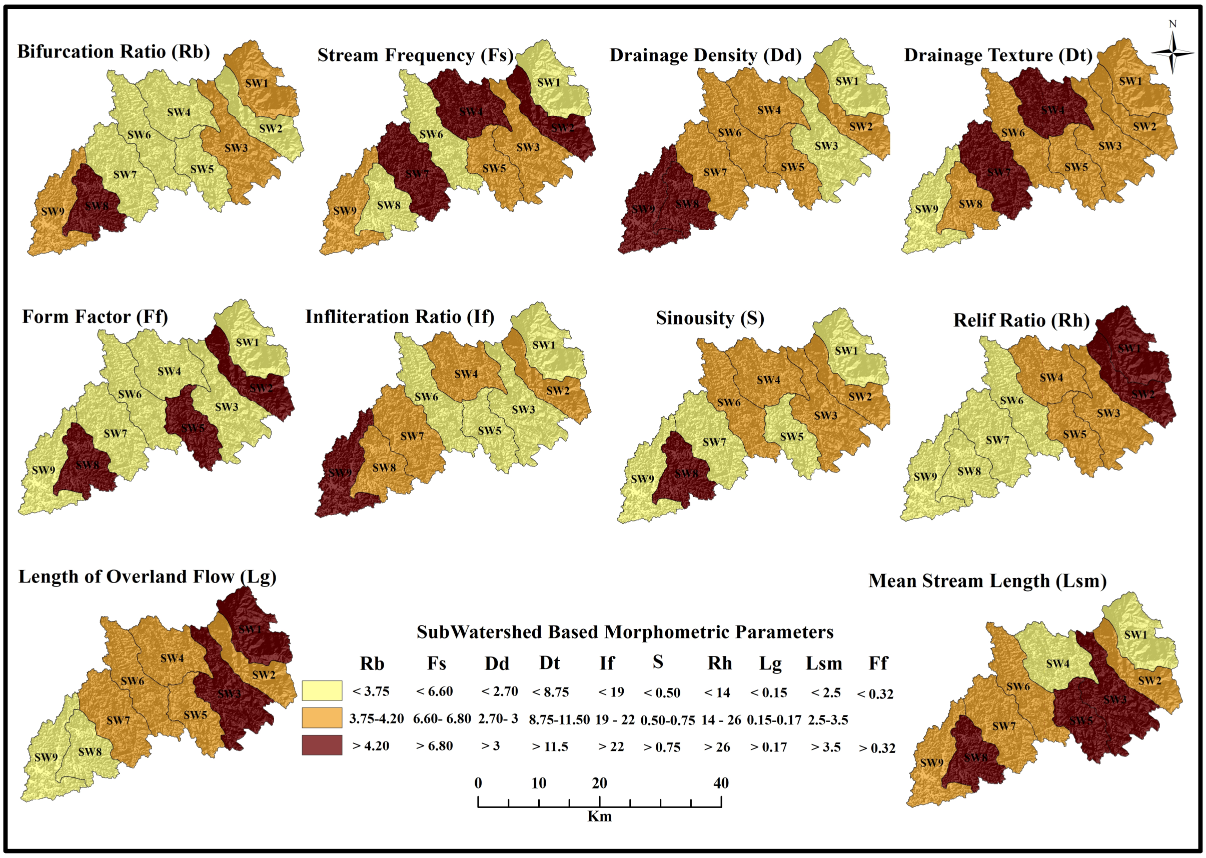

Figure 2: Spatial distribution of morphometric factors influencing flood vulnerability

5. Discussion

The level of vulnerability in each sub-watershed is determined using the morphometric indices. Accordingly, 10 morphometric parameters have been selected which includes Bifurcation ratio (R_b), Mean stream length (L_{sm}), Stream frequency (F_s), Drainage density (D_d), Drainage texture (D_t), Form factor (F_f), Infiltration ratio (I_f), Sinuosity (S), Relief ratio (R_h) and Length of overland flow (L_g). There are several MCDM technique which have been used to prioritize those sub-watersheds for flood vulnerability mapping. However, in this study we have utilized Compound Factor (CF), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and VlseKriterijuska OptimizacijaI Komoromisno Resenje (VIKOR) methods (Figure 3).

Table 2: Flood prioritization of sub-watersheds through CF, TOPSIS and VIKOR

	CF		TOPSIS				VIKOR			
Name	***CF***	***Rank***	S_i^+	S_i^-	P_i	***Rank***	S_i	R_i	Q_i	***Rank***
SW1	*5.3*	*3*	*0.037*	*0.056*	*0.603*	*1*	*0.297*	*0.076*	*0.075*	*2*
SW2	*4*	*8*	*0.038*	*0.040*	*0.508*	*2*	*0.476*	*0.095*	*0.413*	*6*
SW3	*4.4*	*7*	*0.050*	*0.034*	*0.407*	*4*	*0.465*	*0.121*	*0.592*	*7*
SW4	*5.3*	*3*	*0.100*	*0.024*	*0.192*	*9*	*0.322*	*0.065*	*0.028*	*1*
SW5	*5.2*	*5*	*0.052*	*0.030*	*0.368*	*5*	*0.378*	*0.096*	*0.317*	*4*
SW6	*6.6*	*1*	*0.056*	*0.025*	*0.305*	*7*	*0.480*	*0.078*	*0.298*	*3*
SW7	*4.7*	*6*	*0.056*	*0.027*	*0.326*	*6*	*0.433*	*0.092*	*0.344*	*5*
SW8	*3.9*	*9*	*0.049*	*0.047*	*0.486*	*3*	*0.746*	*0.134*	*1.000*	*9*
SW9	*5.6*	*2*	*0.064*	*0.021*	*0.250*	*8*	*0.594*	*0.110*	*0.656*	*8*

5.1. Compound Factor

Compound factor is one of the best methods in prioritizing the sub-watershed for the flood vulnerability. As said earlier there are 10 morphometric parameters were utilized for this prioritization. They are segregated into two as direct and indirect parameters in relation with the flood which includes R_b, L_{sm}, F_s, D_d, D_t as direct and F_f, I_f, S, R_h and L_g as indirect relation, respectively. It is provided that the high values of direct parameters are given high rank and the high values of indirect parameters are given low rank and vice versa. Accordingly, the CF values is calculated by averaging all the direct and indirect parameters. Regarding the CF values the high priority is given to the sub-watershed possessing low CF values and the low priority is given to the sub-watershed possessing high CF values. Here the values of CF are ranging from 4 to 6 as shown in table 2 and categorised into four priority classes as very high (4-4.4), high (4.5-4.9), moderate (5-5.5) and low (5.6-6) (Figure 3). The very high priority class is found in the SW-8 and the high priority class is found in SW-3, SW-7 and SW-9.

5.2. TOPSIS

TOPSIS is totally different from other MCDM method as it is significant in calculating a Euclidean distance of each element of decision makers from a point of ideal best and ideal worst (Hwan and Yoon, 1981). As same as the CF method 10 parameters were taken into account where it is differentiated as beneficial (direct) and nonbeneficial (indirect) criteria. The sub-watershed is prioritized into 4 classes based on closeness coefficient values (P_i) from ideal best (A^+) and ideal worst (A^-). The P_i values of TOPSIS is ranging from 0.20 to 0.60 (Table 2) where the higher value is given higher rank and vice versa. The very high class (0.51-0.60) is found in SW-1, SW-2 and SW-8 whereas the high class (0.41-0.50) is found in SW-3 and SW-5 as shown in figure 3. In comparison with the CF values SW-8 is the common sub-watershed falling under very high priority class.

5.3. VIKOR

VIKOR method is similar as TOPSIS but uses measure of closeness value (Q_i) to ideal alternatives in assigning weights and rank of each alternatives. The Q_i values of VIKOR method is identified with the maximum value of 1 and the minimum value of 0.20 from the analysis as in the table 2. In similar with the previous methods of CF and TOPSIS, the Q_i values are categorised into four classes as very high (0.81-1), high (0.61-0.80), moderate (0.41-0.60) and low (0.20-0.40) (Figure 3). The very high class is marked in the SW-8 and the high class is marked in the SW-3 and SW-9 respectively. While comparing the results of CF, TOPSIS and VIKOR, it is identified that SW-8 in very high priority class and SW-3 in high priority is the common sub-watershed, where the flood vulnerability is very high.

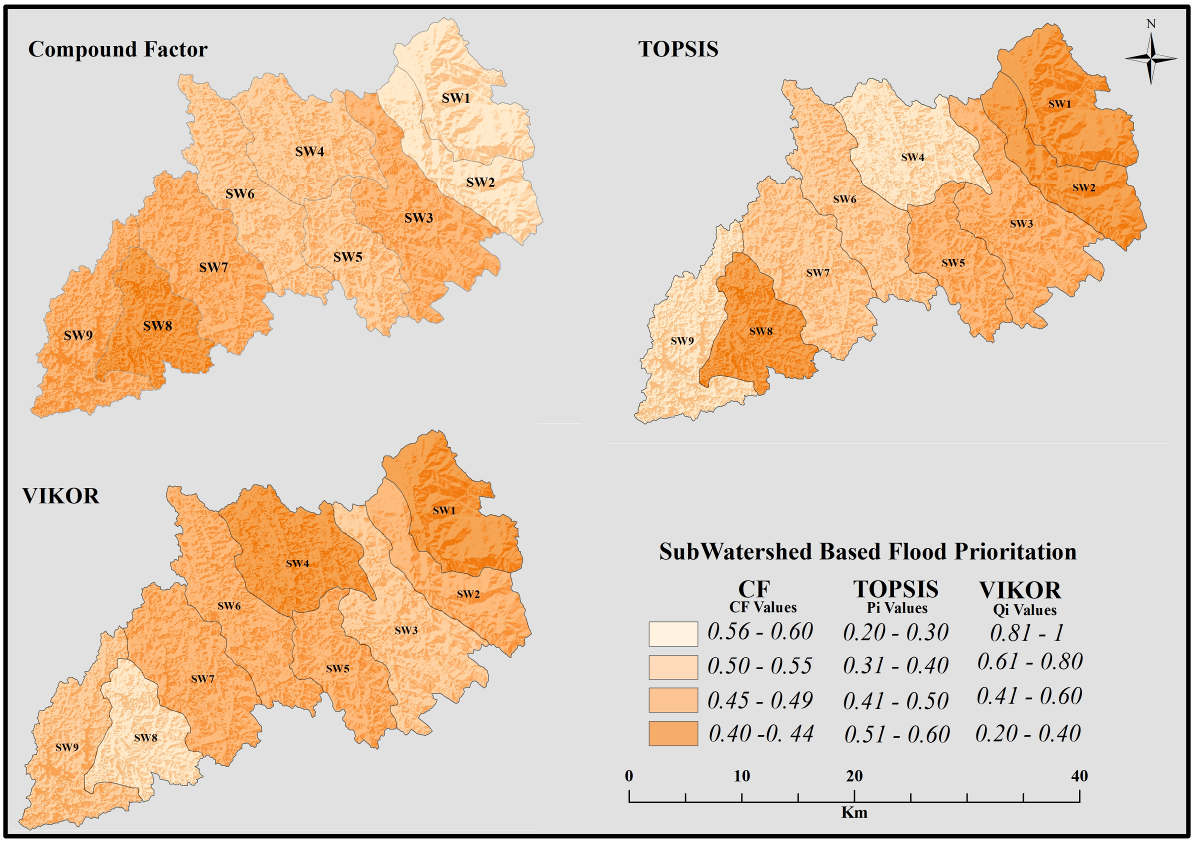

Figure 3: Sub-watershed based flood prioritization through CF, TOPSIS and VIKOR methods

5.4. Validation

As this study utilised CF and MCDM methods (TOPSIS & VIKOR) for prioritizing the sub-watershed prone to flood vulnerability. Its results must be validated using statistical methods for identifying significant methods for flood prioritization in Manimala watershed. However, in the present study one of the non-parametric test of Kendall Tau Correlation Coefficient test (KTCCT) is calculated to find the corelation between the CF and MCDM methods. The results illustrate that TOPSIS and VIKOR shows positive corelation (0.24) (Table 3), which represent similarity in ranking the sub-watersheds (Figure 4), where the corelation between CF & VIKOR, CF & TOPSIS shows a negative corelation (-0.42 & -0.48) respectively. This determines that the MCDM methods are partially similar in ranking the alternatives, between CF and MCDM methods, fully dissimilar to each other as shown in figure 4. Individually performs of CF method is significant in Manimala watershed as it portrays that the SW-7, SW-8 & SW-9 lies in the gentle and flat terrain has high risk is acceptable, but it may vary for different region. In case of MCDM, SW-1 in the high elevated region is showing high vulnerability where the surface runoff is high and restricts flood occurrence. As a result, MCDM methods shows a positive corelation and similarity in ranking but the CF method is best suited for flood mapping in this study region.

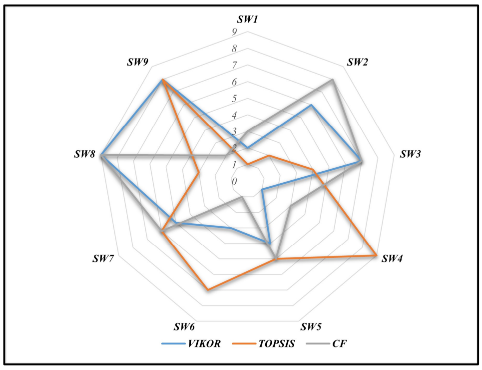

Figure 4: Ranking deviation between CF, TOPSIS & VIKOR

Table 3: Corelation coefficient values (τ) of CF, TOPSIS & VIKOR

	VIKOR	**TOPSIS**	**CF**
VIKOR	*1*	*0.231*	*-0.48*
TOPSIS		*1*	*-0.42*
CF			*1*

6. Conclusion

Flood is the most threatening natural disaster in the recent times due to the climatic change. where its impact must be reduced by identifying the vulnerable zones. Thus, the present study utilises CF, TOPSIS and VIKOR for prioritising the sub-watershed based on flood vulnerability for the Manimala watershed as it is recorded with a greater number of past events of flood. All the values of CF and MCDM methods are categorised into four priority classes regarding flood vulnerability. The results exemplify that very high priority in SW-8 and high priority in SW-3 by comparison of three methods. These results are validated to assess the suitable methods for identifying sub-watershed which is most vulnerable towards flood by using a non-parametric statistical method i.e., KTCCT. The outcomes represent the strong corelation between the MCDM methods and negative relation with the CF. But the CF shows a unique and significant relation in prioritizing sub-watershed on flood vulnerability. Accordingly, SW-7, SW-8 & SW-9 are identified as the extremely vulnerable sub-watershed for flood occurrence and shows high priority, where the continuous monitoring must be tracked and implementation of flood management strategies.

References

1. Ahmed, S, A., Chandrashekarappa K, N., Raj S, K., Nischitha V., Kavitha, G., 2010. Evaluation of morphometric parameters derived from ASTER and SRTM DEM-a study on Bandihole sub-watershed basin in Karnataka. Journal of the Indian Society of Remote Sensing. 38, pp. 227-238.
2. Ameri, A, A., Pourghasemi, H, R., Cerda, A., 2018. Erodibility prioritization of sub-watersheds using morphometric parameters analysis and its mapping: A comparison among TOPSIS, VIKOR, SAW, and CF multi-criteria decision making models. Sci Total Environ 613–614, pp.1385–1400. https://doi.org/10.1016/j.scitotenv.2017.09.210
3. Baumgardner R., 1987. Morphometric studies of sub-humid and semiarid drainage basin. In: Texas Panhandle and Northeastern New Mexico. University of Texas Bureau of Economic Geology, Austin, Report of Investigations; pp.163.
4. Bertolo, F., 2000. Catchment delineation and characterisation, catchment characterisation and modelling Euro landscape project. Space Application Institute, Joint Research Center, Ispra.
5. Chitsaz, N., Banihabib, M, E., 2015. Comparison of different multi criteria decision-making models in prioritizing flood management alternatives. Water Resour. Manag. 29, pp. 2503–2525. https://doi.org/10.1007/s11269-015-0954-6
6. Costache, R., Fontanine, F., Corodescu, E., 2014. Assessment of surface runoff depth changes in Sˇarˇa¸tel River basin, Romania using GIS techniques. Central European Journal

of Geosciences. 6, pp. 363-372.

7. Dingman S.L., 2008. Physical hydrology (2nd ed.). Illinois: Waveland Press Inc.
8. El-Santawy, M.F., 2012. A VIKOR method for solving personnel training selection problem. Int. J. Comput. Sci. 1 (2), pp. 9–12.
9. Fohrer, N., Haverkamp, S., Eckhardt, K., Frede, H.G., 2001. Hydrologic response to land use changes on the catchment scale. Physics and Chemistry of the Earth. 26, pp. 577-582.
10. Gregory K, J, Walling, D, E., 1973. Drainage Basin Form and Process: A Geomorphological Approach. New York: Wiley. 184, pp. 977-978.
11. Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., Kanae, S., 2013. Global flood risk under climate change. Nature Climate Change. 3, pp. 816–821.
12. Horton, R, E., 1932. Drainage-basin characteristics. Transactions, American Geophysical Union 13, pp. 350-361.
13. Horton, R, E., 1945. Erosional Development of Streams and Their Drainage Basins; Hydrophysical Approach to Quantitative Morphology. Geological Society of America Bulletin.56, pp. 275-370.
14. Hwang, C.L., Yoon, K., 1981. Multiple Attributes Decision Making Methods and Applications. Springer, Berlin Heidelberg, pp. 225.
15. Kannan, G., 2009. A hybrid approach using ISM and fuzzy TOPSIS for the selection of reverse logistics provider. Resources, Conservation and Recycling. 1, pp. 28–36. https://doi.org/10.1016/j.resconrec.2009.06.004
16. Nitheshnirmal, S., Thilagaraj, P., Rahaman, S.A. Jegankumar, R. (2019). Erosion risk assessment through morphometric indices for prioritisation of Arjuna watershed using ALOS-PALSAR DEM. Model. Earth Syst. Environ. 5, pp. 907–924. https://doi.org/10.1007/s40808-019-00578-y
17. Opricovic, S., 1998. Multicriteria optimization of civil engineering systems. Faculty of Civil Engineering, Belgrade. 2(1), pp. 5–21
18. Opricovic, S., Tzeng, G.H., 2007. Extended VIKOR method in comparison with outranking methods. Eur. J. Oper. Res. 178, 514–529. https://doi.org/10.1016/j.ejor.2006.01.020
19. Opricovic, S., Tzeng, G-H., 2004. Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. European Journal of Operational Research. 156(2), pp. 445–55. https://doi.org/10.1016/S0377-2217(03)00020-1
20. Schumm, S, A., 1956. Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin 67, pp.597-646.
21. Sofia, G., Roder, G., Dalla Fontana, G., Tarolli, P., 2017. Flood dynamics in urbanised landscapes: 100 years of climate and humans' interaction. Scientific Reports. 7, pp. 40527.
22. Szmidt, E., Kacprzyk, J., 2011. The Spearman and Kendall rank correlation coe_cients between intuitionist fuzzy sets. In Aix-Les-Bains; Atlantis Press: Paris, France, pp. 521–528.
23. Todorovski, L., Džeroski, S., 2006. Integrating knowledge driven and data-driven approaches to modeling. Ecological modelling. 194 (1), pp. 3–13. https://doi.org/10.1016/j.ecolmodel.2005.10.001
24. Venkatesh, R., Abdul Rahaman, S., Jegankumar, R., & Masilamani, P., 2020. Eco-Environmental Vulnerability Zonation In Essence Of Environmental Monitoring And Management, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLIII-B5-2020, pp. 149–155, https://doi.org/10.5194/isprs-archives-XLIII-B5-2020-149-2020