Pak. J. Engg. Appl. Sci. Vol. 33 July, 2025 (p. 70–82)

Watershed Management Using Multicriteria Decision-Making (Mcdm) With Weighted Linear Combination (Wlc) For Selection of Suitable Sites of Check Dams For A Data-Scarce Region

Syed Ali Husnain[1,2] , Ahmad Mujtaba[1*], Zaheer Muhammad Malik[1], Adnan Maqbool[2], Muhammad Kaleem Sarwar[1]

1. *Center of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore.*
2. *Pakistan Engineering Services PVT. Ltd.*

* **Corresponding Author:** Email: engr.dam@yahoo.com

Abstract

Flash flooding due to short duration and high-intensity rainfall is one of the main issues in Panjgur District, a western region of Balochistan in Pakistan. Check dams are often proposed for reducing flood peaks, and flood volumes, preventing soil erosion and harvesting the surface water. The selection of the most suitable sites for check dams within the stream network is always challenging. This study is performed to identify the geographical location of the check dams for a proposed dam. A watershed boundary was identified by using the Archydro tools in the Geographical Information System (GIS) for a proposed dam. For identifying the suitable locations of the check dam, Multi Criteria Decision Making Analysis (MCDMA) technique is used, in which, nine geomorphological and topo-hydrological parameters (Drainage Density, Land use/Land cover, Stream Order, Topographic Wetness Index, Topographic Position Index, Slope, Terrain Ruggedness Index, Topographical Wetness Index, Stream Power Index, and Sediment Transport Index) were analyzed and classified using GIS. The weightage factor is assigned to each parameter. By using the Weighted Linear Combination (WLC) method, the locations of the check dams are identified. The results showed that the elevation changes from 1047 to 2058m covering an area of 4458.75km^2 in the proposed dam watershed. The slope ranges from 0^o to 59.63^o. The majority of the study area fell into quality zones with moderate to good potential for check dam construction. Based on the findings, 137 suitable locations for the check dams are identified. This study will help policymakers in the Panjgur District for the sustainable management of water management by expanding their understanding of the role of spatial data analysis.

Keywords: Panjgur; Proposed Dam; MCDMA; WLC; Watershed Delineation; Flash Floods

1 Introduction

Flash floods are a major problem in Balochistan (Fig.1), as they can cause significant damage to the property and people living there [1]. When heavy rains fall on a region that has been unable to absorb the water adequately owing to urbanization or other environmental issues, flash flooding can occur quickly [2], [3]. As a result, a lot of water runs off all at once, which can cause the drainage system to overflow and produce damage [4], [5]. An easy-to-build barrier, the check dam slows down the water flow to prevent flooding, preserve soil, and keep river levels stable [6], [7]. It's a great method for preventing flood damage and preserving farmland's soil moisture [8], [9]. Although check dams have been used by engineers ever since ancient times, advancements in technology have allowed for far more precise pinpointing of ideal sites [10]. Flood flows in rivers and streams at various elevations along their courses were previously simulated by engineers using different hydrological models like HEC-RAS [11] or FLO2D [12], [13]. Hydrological models are based on mathematical equations that incorporate data from topographic maps [14] and other sources such as rainfall records. The output from these models can be used by engineers to select suitable sites where the construction of a check dam would be most beneficial for controlling floods or conserving soil moisture levels downstream. Nowadays, geospatial techniques such as remote sensing images combined with Geographic Information Systems (GIS) analysis help in determining the potential sites for constructing a new check dam [15], [16]. These techniques allow us to assess physical characteristics like slope, and land use/land cover in the area of interest as well as topographical features like valleys or ridges which may influence the flow of water through the landscape [15], [16].

Field visits are essential when selecting potential sites for check dams because they allow engineers to observe and survey the terrain firsthand and gather additional information that cannot be obtained from remotely sensed images or technical models alone [7], [8]. By combining GIS analysis with hydrological modeling results it becomes possible to identify the sites where a check dam might provide the most benefit in regards to controlling floods or conserving soil moisture levels downstream of the dam location. However, constructing check dams is a difficult task due to various problems faced by engineers during the process. The most significant issues include hydrological and topographical conditions, financial constraints, environmental impacts, and social acceptance [6].

Land use/land cover, stream network, geomorphological, and topo-hydrological factors play an important role in determining whether or not a check dam is feasible for construction at any given site [19], [20]. Multi Criteria Decision Making Analysis (MCDMA) technique is widely used and has been successfully applied across many sectors including environmental impact assessment (EIA), urban planning projects, and resource allocation schemes for determining the suitable locations for check dams. This technique offers significant advantages over conventional approaches by allowing complex problems involving multiple competing interests or objectives to be resolved quickly yet effectively. Therefore, this research is conducted to identify the possible watershed boundary of the Proposed Panjgur Dam and identification of locations of the possible check dams within the watershed boundary by using the Multi-Criteria Decision Making (MCDM) technique in GIS [16], [21].

2 Methodology

2.1 Study Area

To check the extent of the study area, the Arc-hydro tool was used, which was developed by the Environmental Systems Research Institute (ESRI) for watershed delineation and hydrologic analysis [22], [23]. By using this tool at the proposed location of the Panjgur Dam, the watershed is delineated. The first step in using Arc-hydro tools was the selection of a digital elevation model (DEM) then it was used within ArcGIS Desktop software where several different tools were used for calculating catchment areas, stream networks, flow paths along with other related parameters that helped in engineering decisions on mitigating flood risks or designing water management systems [24]. There are a lot of DEM available online, in this research, the Shuttle Radar Topography Mission (SRTM) was used because of its higher accuracy [25], [26], [27] which allowed to make informed decisions about the watershed characteristics like upstream contributing areas size distributions among others without having any negative impacts on the environment beforehand [28]. A detailed methodology for performing the watershed delineation is shown in Fig.2. After watershed delineation, the elevations and the watershed boundary of the proposed Panjgur dam location are shown in Fig.3.

2.2 Multi-Criteria Decision-Making Analysis (MCDMA)

Identification of the check dam locations in Panjgur watershed is carried out by using the Multi Criteria Decision Making Analysis (MCDMA) technique. This technique involves problem formulation, identifying the requirements of the project, setting goals, developing criteria, and identifying and applying the decision-making technique. This

(a) Flood severity in Balochistan [17]

(b) Flooding in Panjgur [18]

Fig. 1: Photographs showing the severity of the flash flood in Panjgur – Balochistan

analysis allows for the evaluation of multiple criteria simultaneously, to make more informed decisions about which sites are most suitable. In this research, several factors are considered that may influence the effectiveness within the watershed boundary, including Stream Order (SO), Drainage Density (DD), Slope, Landuse/landcover (LULC), Stream Power Index (SPI), Sediment Transport Index (STI), Topographic Position Index (SPI), Terrain Ruggedness Index (TRI), and Topographic Wetness Index (TWI) [29]. These criteria are then weighted according to their relative importance before being evaluated against each other on an individual basis; ensuring all relevant information is taken into account when making final decisions regarding potential sites for check dams.

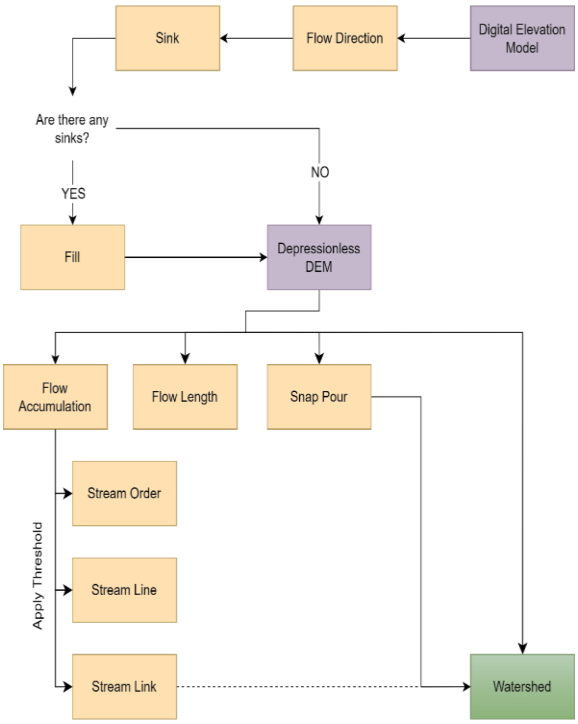

Fig. 2: Flow chart for the watershed delineation using Arc-Hydro Tools

2.3 Identification of check dam locations

2.3.1 Geomorphological and Topo-hydrological Factors

Stream Order (SO)

Streams with a greater stream order typically experience much larger floods. Stream

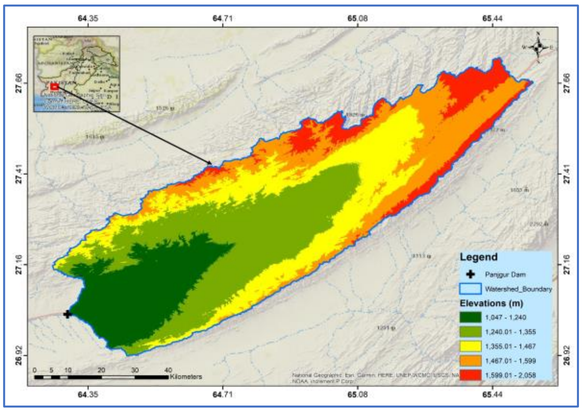

Fig. 3: Topographical variation in watershed boundary

Stream order is selected as one of the criteria for locating appropriate check dam locations. The Arc-hydro Tools in ArcGIS were used to create this [30], [31], [32].

Slope

Water flow is affected by many different topographical features, but one of the most important is slope. If the slope is steeper, more water will flow down it and more will accumulate, making the area more prone to flooding and sediment transfer. ArcGIS's Spatial Analyst Tool is used to calculate an approximation of the slope [33], [34].

Topographic Wetness Index (TWI)

The TWI is a topo-hydrological factor used to measure the influence of terrain on water flow. Hydrological processes at the watershed scale are directly impacted by the TWI's command over the spatial pattern of saturated areas. It is a function of both the slope and the region that contributes to it [35], [36].

$$TWI = \ln\left(\frac{a}{\tan b}\right) \tag{1}$$

$a = specific\ upslope\ area\ draining\ through\ a\ certain\ point\ per\ unit\ contour\ length\ \left(\frac{m^2}{m}\right)$

$b = slope\ gradient\ (degrees)$

Terrain Ruggedness Index (TRI)

At the watershed scale, the TRI is a major determinant of Stream Energy, surface storage capacity, runoff velocity, and routing. Differences in elevations between adjacent cells in GIS are quantified by the TRI [37], [38].

$$TRI = \frac{TNC \times TNF}{TNC + TNF} \tag{2}$$

$TNC = total\ number\ of\ contours\ intercepts\ along\ the\ transect$

$TNF = total\ number\ of\ fluctuations\ (ups\ and\ downs)$

Topographic Position Index (TPI)

Runoff production, flow velocity, and sediment movement are all affected by the topography of the land. TPI analyses digital elevation maps by comparing the elevation of each cell to the average elevation of a certain neighborhood. As the TPI grows, steeper places become flatter ones [39], [40], [41].

$$TPI = Z_o - \frac{\sum_{1-n} Z_n}{n} \quad (3)$$

$Z_o = elevation\ of\ the\ point\ under\ evaluation$

$Z_n = elevation\ of\ the\ point\ within\ the\ local\ window$

$n = total\ number\ of\ surrounding\ points$

Land use/landcover

The LULC pattern was categorized as built area, crops, scrub/shrubs, and snow/ice. They all have the unique characteristics of recharge and runoff [42], [43], [44]. It was developed by using the remote sensing technique by following the flowchart (Fig.4).

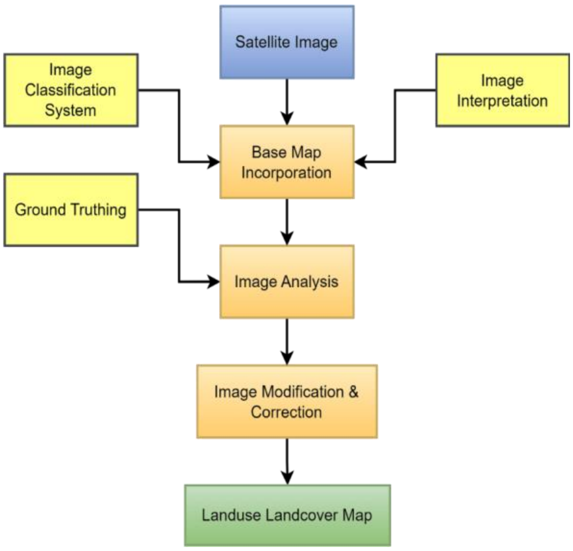

Fig. 4: Flow chart for development of Land use/Landcover map

Sediment Transport Index (STI)

Important data on sediment transport potential in the stream network can be gathered from the STI. It's used to describe erosion and deposition processes while taking topography into account [15], [29], [45].

$$STI = \left(\frac{A_s}{22.13}\right)^{0.6} \times \left(\frac{\sin\beta}{0.0896}\right)^{1.3} \quad (4)$$

$A_s = upstream\ area$

$\beta = slope\ at\ a\ given\ cell$

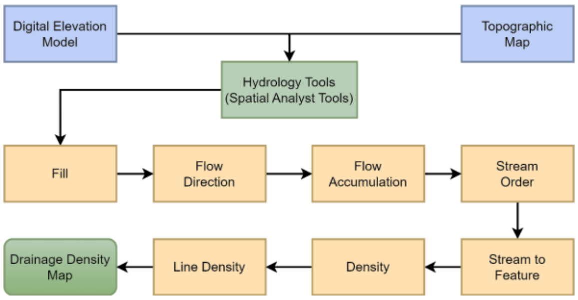

Fig. 5: Flow chart for development of drainage density map

Stream Power Index (SPI)

Stream power, shear stress, and velocity all play crucial roles in determining the extent of flood damage and river channel erosion. SPI assesses the erosive potential of overland flow as a product of catchment area and slope [46], [47].

$$SPI = A_s \tan\beta \quad (5)$$

$A_s = upstream\ area$

$\beta = slope\ at\ a\ given\ cell$

Drainage Density (DD)

In addition to influencing the peak flow's amplitude and concentration duration, drainage density plays a significant role in flooding, with reduced drainage density typically resulting in lower flood volumes [19], [48], [49]. It was developed by using the Arc-hydro Tools (Fig.5) and Spatial Analyst Tools in ArcGIS.

2.3.2 Thematic Layer Handling

Nine geomorphometric and topo-hydrological components were included in the GIS as potential predictive variables: TWI, TRI, TPI, STI, SPI, slope, DD, LULC, and SO. The final maps for all of the variables are shown in Fig.7. Expert groups with knowledge and expertise in controlling surface runoff, soil erosion, sediment transport, and flood hazards provided pairwise comparison ratings that served as the basis for the weighting values. Each category was given a score based on how much of an impact it has on the probability of flooding. It was decided to use S values from 1 to 5, where S = 1 indicates the least flood susceptibility and S = 2 through 5 indicates the highest. Based on the professional assessment of class influence on flood vulnerability, each component was further categorized in a GIS environment and assigned a score from 1 to 5 (lowest to greatest priority) (Fig.8 and Fig.9).

2.3.3 MCDMA Technique for Suitable Locations

The Analytical Hierarchy Process (AHP) is a well-known method for making multi-criteria choices by comparing and ranking their relative importance. An AHP analysis begins with the prioritization of the decision-making factors (the aim, the criteria, and the alternatives). AHP is well suited method for flood susceptibility, the studies referenced applied the same AHP techniques on a limited scale like [50], [51], [52], [53], focusing on a single watershed and a small number of counties. Additionally, they utilized a limited number of criterion factors. We utilized nine factors, a pairwise comparison matrix of the criteria is developed to figure out how important each factor is. The 1–9 scale was used to show the relative dominance of one element over another for each criterion. Following the relative weight of the various factors, Fig.6 shows the priorities of a weighted overlay analysis, which were used to calculate an estimated CR.

$$CR = \frac{CI}{RI} \quad (6)$$

$$CI = \frac{\lambda - n}{n-1} \quad (7)$$

If the matching CR is less than 10%, then the judgment matrix is consistent enough [54]. To see how consistent the evaluations were compared to random evaluations, the consistency ratio (CR) was computed and found to be 0.07.

3 Results and Discussion

3.1 Criteria Weights

By using the above scale, weights are assigned to the criteria (geomorphological and topo-hydrological factors) based on their importance in the location of dam selection. A pairwise comparison matrix is tabulated in Table 1 and the criteria weights are tabulated in Table 2. The weightage for each parameter is estimated by dividing the matrix value of each parameter by the sum of all parameters. The Table 1 illustrates the pairwise comparison matrix, which allows us to assess the relative importance of each factor by comparing them two at a time. This method is essential for establishing a hierarchy among the factors based on expert judgment, ensuring that the most influential parameters are prioritized in our analysis. Following this, the Table 2 presents the normalized matrix, which transforms the raw comparison values into a scale that reflects the

Fig. 6: Basic scale for Precedence of factors [29]

relative weight of each parameter. This normalization process is crucial as it facilitates a clearer understanding of how each factor contributes to the overall assessment, enabling more informed decision-making in the context of our research objectives. By employing these methodologies, we aim to provide a robust framework for evaluating the interplay between these environmental factors and their implications for our study.

3.2 Thematic Layers and Suitable Sites for Check Dam

Streams with a greater stream order typically experience much larger floods because of this factor. All streams that do not have any tributaries are given a rank of 1 in the stream order. A second-order stream is created when two first-order streams meet. When two streams come together upstream, the one coming downstream will have the higher order of the two streams coming together. Since order-1 streams are typically the smallest and the construction of check dams in them is rarely cost-effective, they were given the lowest possible score (of 1). Thus, second-order streams were given the greatest score (5), whereas higher-order streams (up to and including sixth-order streams) were given the lowest value (1). Maximum TWI was given the highest score (5), with the ranking dropping with decreasing TWI, so that minimal TWI obtained a ranking of 1. This is because the value of TWI falls as the contributing area decreases, making the construction of check dams less of a priority. Ullah and Zhang (2020) found that a higher TWI class was associated with increased flooding likelihood [55]. Maximum TRI was given the highest score (5), with the ranking reducing with decreasing TRI, so that least TRI obtained a ranking of 1. Since TRI is always zero if the surface is flat, the importance

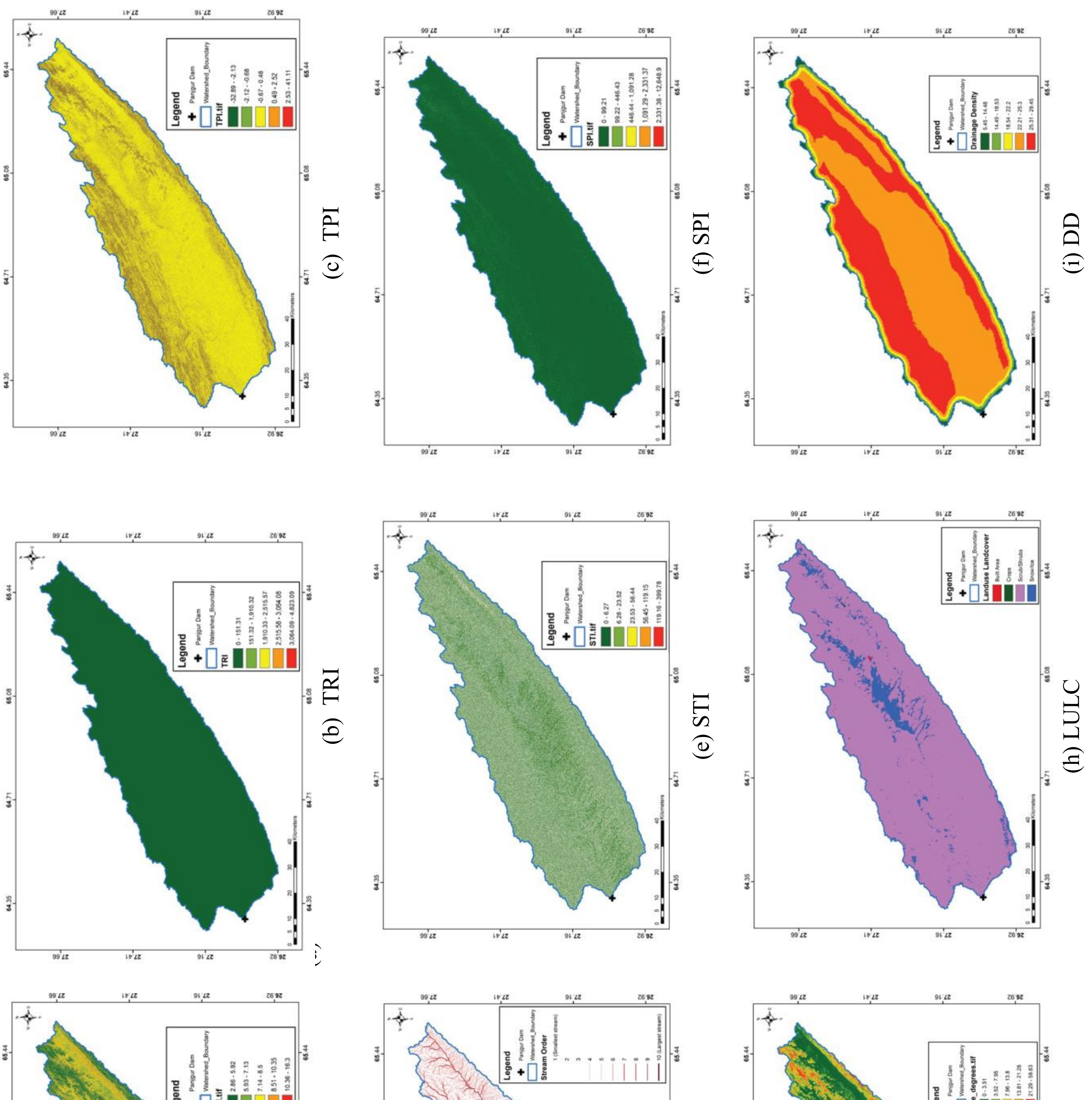

Fig. 7: Results for all factors in proposed watershed boundary

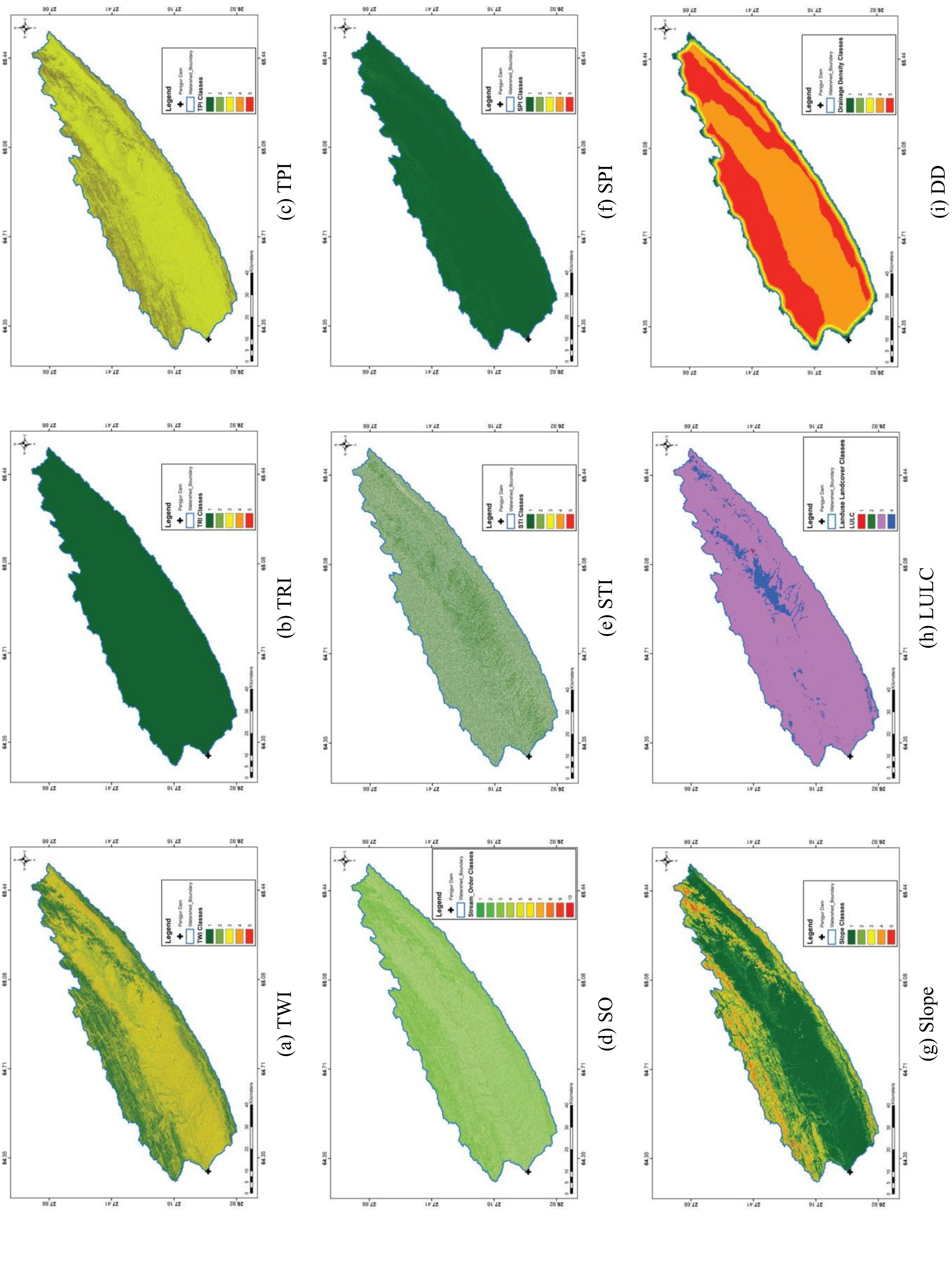

Fig. 8: Assigned score for all factors in the proposed watershed boundary

of the construction of check dams diminishes as TRI lowers. The highest score (5) was given to minimum TPI, with the ranking reducing with rising TPI so that maximum TPI obtained a ranking of 1. Since an increase in TPI causes a shifting of steep regions into flat areas, the importance of the construction of check dams lowers. Similarities can also be seen between the stream order features [56]. The LULC pattern was categorized as Herbaceous cover, deciduous shrubland, grassland, sparse vegetation, bare areas, and unconsolidated bare areas. This study also has similar characteristics [57]. These all features have the unique characteristics of recharge and runoff. In this case, agricultural land has a higher priority than other categories. To characterize erosion and deposition processes, the STI takes topography into account. Since a low STI value has less of an impact on erosion and deposition, the maximum STI value was given the greatest score (5), and the minimum STI value was given the lowest score (1). Since SPI is the product of catchment area and slope and measures the erosive potential of overland flow, we ranked SPI values from 1 to 5 with 5 being the highest and 5 the lowest. Steeper slopes are given more weight because they increase the likelihood of floods and sediment transport due to the increased speed and volume of water flowing down them. The concentration time is affected by drainage density, and thus the peak flow amplitude. Areas with the highest DD received the best possible rankings. GIS techniques are very well adopted for flood susceptibility, Abdelkareem, 2017 also utilized GIS techniques to deliver insights on the physical characteristics of catchments [58].

3.3 Suitable Sites for Check Dams

The Weighted Linear Combination (WLC) technique was used to get the final forecast of suitable check dam locations. Based on the same intervals of results, the final map was divided into five categories of suitability: bad, fair, moderate, good, and exceptional as shown in Fig.11. The results showed that most of the locations are under the moderate and good zones. This analysis identified about 137 highest priority locations of check dams after imposing the possible locations of check dams on the stream network.

The research presented in this paper is subject to several limitations that must be acknowledged. Firstly, the reliance on expert judgment in the pairwise comparison matrix introduces a degree of subjectivity, which can lead to biases in the assessment of the relative importance of factors such as slope, stream order, and various indices. Maintaining consistency in these comparisons can be challenging, particularly when dealing with multiple complex parameters, potentially skewing results. The computational complexity increases with the number of parameters, making it difficult to ensure precision and reliability throughout the analysis.

4 Conclusions

In the watershed of the proposed Panjgur Dam in Balochistan, areas for check dams and potential construction locations have been pinpointed. The optimum number of check dams for the area under consideration was also determined. This study used a Multi-Criteria Decision-Making Analysis (MCDMA) approach called the Analytical Hierarchy Process (AHP) to address the complicated issue of dam site selection based on a variety of considerations. To quantify concrete aspects with varying priorities, AHP offers a robust and versatile tool that compares two variables side by side. The use of GIS allowed for the deployment of AHP to be better visible in terms of both measurement and presentation. The research found that a total of 137 locations were suitable for the check dams. According to the results of this research, a realistic and strong framework may be found in the use of multi-criteria analysis in a GIS environment with pertinent thematic layers to locate ideal locations for check dams. Water planners and decision-makers may use the findings of this study to better solve water scarcity in the region.

5 References

[1] Mazari, H., Baloch, I., Thinley, S., Kaye, T., & Perry, F. (2022). Learning continuity in response to climate emergencies. https://doi.org/10.53832/edtechhub.0134

[2] Nadeem, A., Sahito, A. M., & Shahid, S. (2022). Flood crisis in Pakistan: A mass destruction to economy and fragile health care systems. Medicine, Conflict and Survival, 1–5. https://doi.org/10.1080/13623699.2022.2157587

[3] Mazari, H., Baloch, I., Thinley, S., Kaye, T., & Perry, F. (2022). Learning continuity in response to climate emergencies. https://doi.org/10.53832/edtechhub.0134

[4] Nadeem, A., Sahito, A. M., & Shahid, S. (2022). Flood crisis in Pakistan: A mass destruction to economy and fragile health care systems. Medicine, Conflict and Survival, 1–5. https://doi.org/10.1080/13623699.2022.2157587

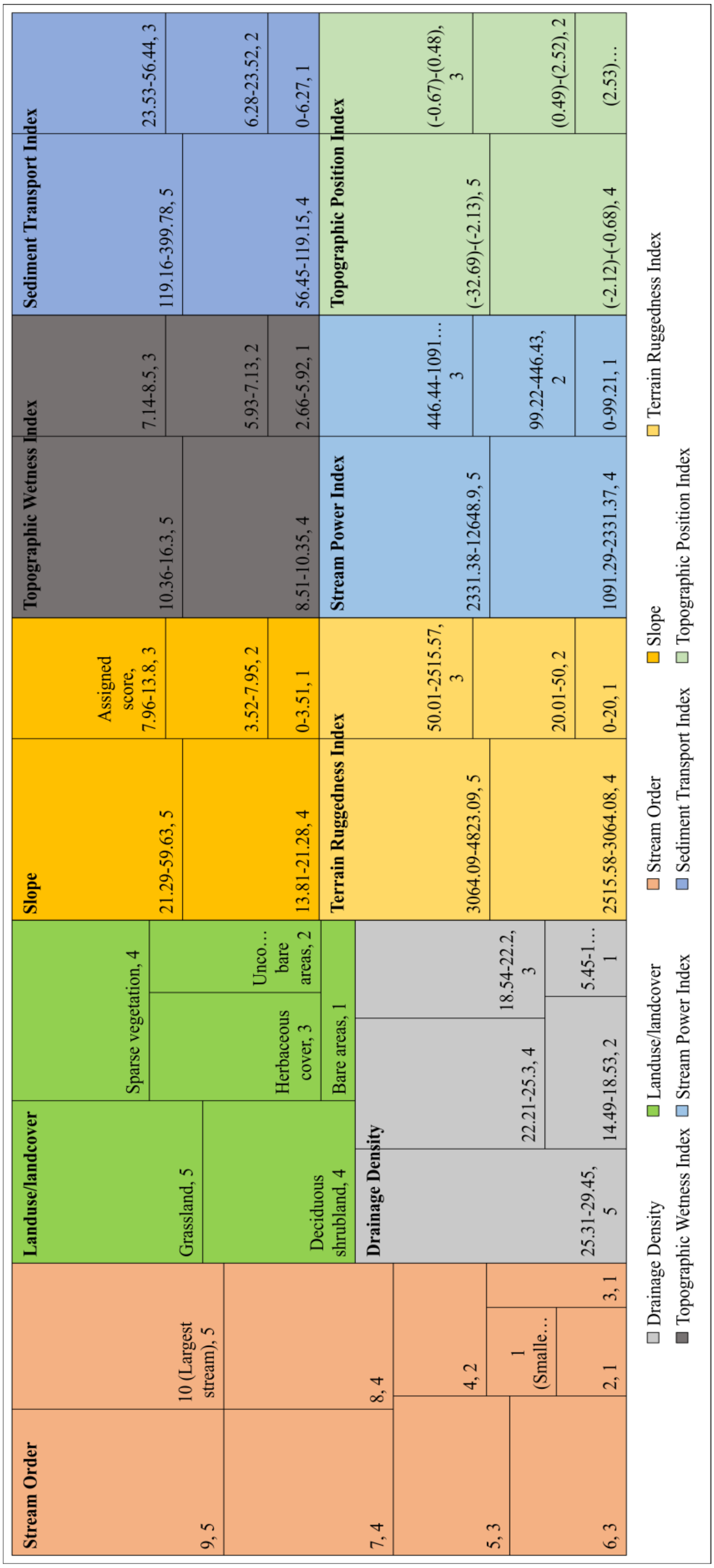

Fig. 9: Assigned and normalized score for all the factors (Text in the boxes represents the class, assigned score while the box size represents the normalized score)

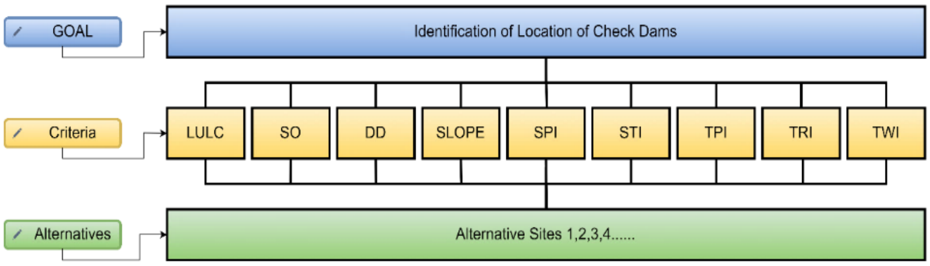

Fig. 10: Flow chart showing the site identification for check dam

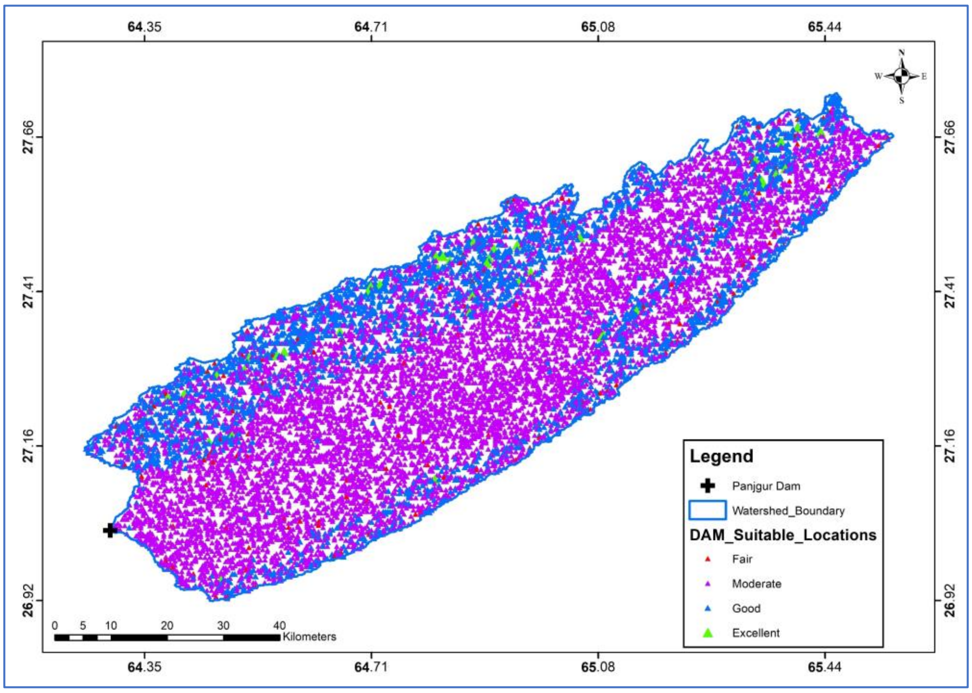

Fig. 11: Possible locations of check dams within the watershed

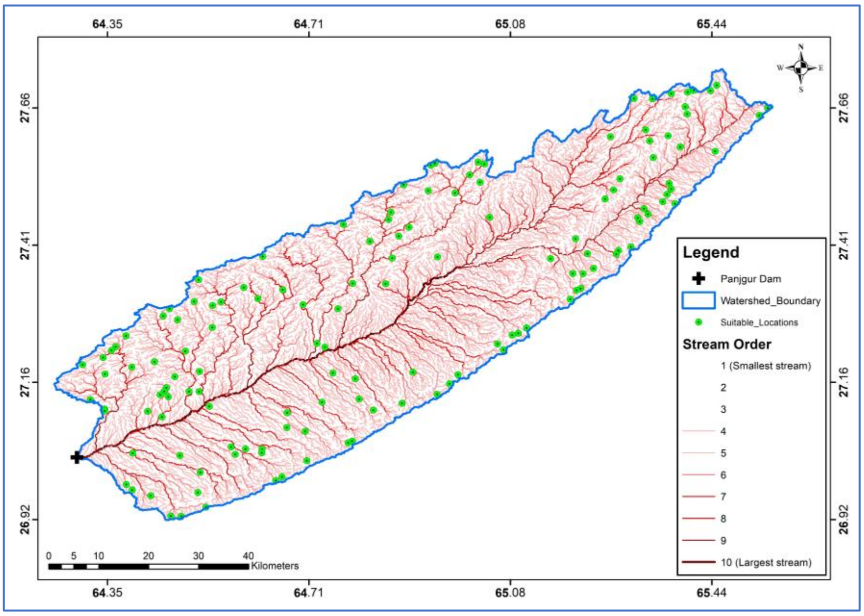

Fig. 12: Potential locations of check dams within the watershed

Table 1: Pairwise comparison matrix of all nine factors

Factor	Slope	SO	LULC	STI	SPI	TPI	TRI	TWI	DD
Slope	1	2	3	4	4	9	9	9	3
SO	0.5	1	0.5	3	4	7	7	7	2
LULC	0.33	2	1	2	3	6	6	6	2
STI	0.25	0.33	0.5	1	2	0.5	0.5	0.5	0.5
SPI	0.25	0.25	0.33	0.5	1	2	2	2	0.5
TPI	0.11	0.14	0.17	2	0.5	1	2	3	0.5
TRI	0.11	0.14	0.17	2	0.5	0.5	1	2	0.5
TWI	0.11	0.14	0.17	2	0.5	0.33	0.5	1	0.5
DD	0.33	0.5	0.5	2	2	2	2	2	1

Table 2: Normalized matrix for each parameter

Parameters	Slope	SO	LULC	STI	SPI	TPI	TRI	TWI	DD	Weights
Slope	0.33	0.31	0.47	0.22	0.23	0.32	0.3	0.28	0.29	0.3
SO	0.17	0.15	0.08	0.16	0.23	0.25	0.23	0.22	0.19	0.19
LULC	0.11	0.31	0.16	0.11	0.17	0.21	0.2	0.18	0.19	0.18
STI	0.08	0.05	0.08	0.05	0.11	0.02	0.02	0.02	0.05	0.05
SPI	0.08	0.04	0.05	0.03	0.06	0.07	0.07	0.06	0.05	0.06
TPI	0.04	0.02	0.03	0.11	0.03	0.04	0.07	0.09	0.05	0.05
TRI	0.04	0.02	0.03	0.11	0.03	0.02	0.03	0.06	0.05	0.04
TWI	0.04	0.02	0.03	0.11	0.03	0.01	0.02	0.03	0.05	0.04
DD	0.11	0.08	0.08	0.11	0.11	0.07	0.07	0.06	0.1	0.09

$$\boldsymbol{\lambda = 9.8165, CI = 0.102, CR = 0.07}$$

[5] Sarkar, S. (2022). Pakistan floods pose serious health challenges. BMJ, 1–2. https://doi.org/10.1136/bmj.o2141

[6] Lama, A. P., & Tatu, U. (2022). Climate change and infections: Lessons learnt from recent floods in Pakistan. New Microbes and New Infections, 49–50, 101052. https://doi.org/10.1016/j.nmni.2022.101052

[7] Iqbal, M., Rabbani, A., Haq, F., & Bhimani, S. (2022). The floods of 2022: Economic and health crisis hits Pakistan. Annals of Medicine and Surgery, 84, 104800. https://doi.org/10.1016/j.amsu.2022.104800

[8] Chen, H. X., Li, J., Feng, S. J., Gao, H. Y., & Zhang, D. M. (2019). Simulation of interactions between debris flow and check dams on three-dimensional terrain. Engineering Geology, 251, 48–62. https://doi.org/10.1016/j.enggeo.2019.02.001

[9] Shi, P., Zhang, Y., Ren, Z., Yu, Y., Li, P., & Gong, J. (2019). Land-use changes and check dams reducing runoff and sediment yield on the Loess Plateau of China. Science of the Total Environment, 664, 984–994. https://doi.org/10.1016/j.scitotenv.2019.01.430

[10] Bai, L., Wang, N., Jiao, J., Chen, Y., Tang, B., Wang, H., Chen, Y., Yan, X., & Wang, Z. (2020). Soil erosion and sediment interception by check dams in a watershed for an extreme rainstorm on the Loess Plateau, China. International Journal of Sediment Research, 35(4), 408–416. https://doi.org/10.1016/j.ijsrc.2020.03.005

[11] Yuan, S., Li, Z., Li, P., Xu, G., Gao, H., Xiao, L., Wang, F., & Wang, T. (2019). Influence of check dams on flood and erosion dynamic processes of a small watershed in the Loess

Plateau. Water, 11(4), Article 0834. https://doi.org/10.3390/w11040834

[12] Alfonso-Torreño, A., Gómez-Gutiérrez, Á., Schnabel, S., Lavado Contador, J. F., de Sanjosé Blasco, J. J., & Sánchez Fernández, M. (2019). sUAS, SfM-MVS photogrammetry and a topographic algorithm method to quantify the volume of sediments retained in check-dams. Science of the Total Environment, 678, 369–382. https://doi.org/10.1016/j.scitotenv.2019.04.332

[13] Namara, W. G., Damisse, T. A., & Tufa, F. G. (2021). Application of HEC-RAS and HEC-GeoRAS model for flood inundation mapping: The case of Awash Bello Flood Plain, Upper Awash River Basin, Oromiya Regional State, Ethiopia. Modeling Earth Systems and Environment, 2015. https://doi.org/10.1007/s40808-021-01166-9

[14] Qiang, Y., Wang, G., Li, R., Ding, W., Gao, Y., & Hanle, L. (2021). Risk assessment of geological hazards in mountain town scale based on FLO-2D and GIS. IOP Conference Series: Earth and Environmental Science, 861(5), 052042. https://doi.org/10.1088/1755-1315/861/5/052042

[15] Jo, H.-I., & Jun, K.-W. (2022). A study on the application of FLO-2D model for analysis of debris flow damage area. Journal of Korean Society of Disaster and Security, 15(June), 37–44.

[16] Rangari, V. A., Umamahesh, N. V., & Bhatt, C. M. (2019). Assessment of inundation risk in urban floods using HEC-RAS 2D. Modeling Earth Systems and Environment, 5(4), 1839–1851. https://doi.org/10.1007/s40808-019-00641-8

[17] Ettazarini, S. (2021). GIS-based land suitability assessment for check dam site location using topography and drainage information: A case study from Morocco. Environmental Earth Sciences, 80(17), Article 554. https://doi.org/10.1007/s12665-021-09881-3

[18] Alene, A., Yibeltal, M., Abera, A., Andualem, T. G., & Lee, S. S. (2022). Identifying rainwater harvesting sites using integrated GIS and a multi-criteria evaluation approach in semi-arid areas of Ethiopia. Applied Water Science, 12(10), Article 267. https://doi.org/10.1007/s13201-022-01756-7

[19] Tribune. (2022). Balochistan cut off as devastating floods wreak havoc. The Express Tribune. https://tribune.com.pk/story/2373100/balochistan-cut-off-as-devastating-floods-wreak-havoc

[20] Nation. (2022). Balochistan floods kill 111, wash away 6,700 homes. The Nation. https://www.nation.com.pk/29-Jul-2022/balochistan-floods-kill-111-wash-away-6-700-homes

[21] Ahirwar, S., Malik, M. S., Ahirwar, R., & Shukla, J. P. (2020). Identification of suitable sites and structures for artificial groundwater recharge for sustainable groundwater resource development and management. Groundwater for Sustainable Development, 11, 100388. https://doi.org/10.1016/j.gsd.2020.100388

[22] Chiu, Y. F., Tfwala, S. S., Hsu, Y. C., Chiu, Y. Y., Lee, C. Y., & Chen, S. C. (2021). Upstream morphological effects of a sequential check dam adjustment process. Earth Surface Processes and Landforms, 46(13), 2527–2539. https://doi.org/10.1002/esp.5178

[23] Galea, S., & Abdalla, S. M. (2020). COVID-19 pandemic, unemployment, and civil unrest: Underlying deep racial and socioeconomic divides. JAMA, 324(3), 227–228. https://doi.org/10.1001/jama.2020.11132

[24] UNDP. (2022). Pakistan floods 2022: UNDP Pakistan's Response and Recovery Plan. United Nations Development Programme. https://reliefweb.int/report/pakistan/pakistan-floods-2022-undp-pakistans-response-and-recovery-plan

[25] Pak-EPA. (2022). Pakistan flood response: Environmental monitoring report. Pakistan Environmental Protection Agency. https://www.epa.gov.pk/pakistan-flood-response-2022

[26] WHO. (2022). Floods in Pakistan: WHO scales up response to health crisis. World Health Organization. https://www.who.int/news/item/07-09-2022-floods-in-pakistan-who-scales-up-response-to-health-crisis

[27] UNICEF. (2022). Pakistan floods 2022: UNICEF situation report No. 5. United Nations International Children's Emergency Fund.

https://www.unicef.org/appeals/files/UNICEF_Pakistan_Flood_SitRep_No._5_-_10_October_2022.pdf

[28] FAO. (2022). Pakistan floods 2022: Impact on agriculture and food security. Food and Agriculture Organization of the United Nations. https://www.fao.org/emergencies/resources/documents/resources-detail/en/c/1600304/

[29] ReliefWeb. (2022). Pakistan: 2022 Floods Response Plan (August 2022–May 2023). https://reliefweb.int/report/pakistan/pakistan-2022-floods-response-plan-august-2022-may-2023

[30] NADRA. (2022). Disaster response and relief efforts in Pakistan floods 2022. National Database & Registration Authority. https://www.nadra.gov.pk/disaster-response-and-relief-efforts-pakistan-floods-2022/

[31] UN OCHA. (2022). Pakistan floods: Situation report No. 10 (As of 10 October 2022). United Nations Office for the Coordination of Humanitarian Affairs. https://reliefweb.int/report/pakistan/pakistan-floods-situation-report-no-10-10-october-2022

[32] WFP. (2022). Pakistan flood emergency: Situation report #8. World Food Programme. https://www.wfp.org/publications/pakistan-flood-emergency-situation-report-8

[33] ADB. (2022). ADB provides $3 million grant to support Pakistan's flood response. Asian Development Bank. https://www.adb.org/news/adb-provides-3-million-grant-support-pakistan-flood-response

[34] Ahmad, S., Kazmi, S. F., & Perveen, S. (2022). Climate change-induced floods and their impact on public health in Pakistan. International Journal of Environmental Research and Public Health, 19(20), 13256. https://doi.org/10.3390/ijerph192013256

[35] UN Women. (2022). Pakistan floods 2022: Gender equality and social inclusion in crisis response. https://pakistan.unwomen.org/en/digital-library/publications/2022/09/pakistan-floods-2022

[36] IRC. (2022). Pakistan floods: Humanitarian response plan and health needs. International Rescue Committee. https://www.rescue.org/resource/pakistan-floods-response-health-and-humanitarian-needs

[37] NDMA. (2022). Post-disaster needs assessment (PDNA) 2022: Pakistan floods. National Disaster Management Authority. https://cms.ndma.gov.pk/public/uploads/Pakistan_PDNA_2022.pdf

[38] UNICEF. (2022). Pakistan Humanitarian Situation Report No. 8 (December 2022). https://www.unicef.org/documents/pakistan-humanitarian-situation-report-no-8-december-2022

[39] World Bank. (2022). Pakistan flood damages and economic loss assessment: August–October 2022. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099231211292242154/pakistan-flood-damages-and-economic-loss-assessment-august-october-2022

[40] International Monetary Fund. (2022). IMF supports Pakistan's flood recovery plan. https://www.imf.org/en/News/Articles/2022/11/22/pr22387-pakistan-imf-supports-flood-recovery

[41] IOM. (2022). Pakistan Floods: Displacement Tracking Matrix (DTM) Situation Overview. International Organization for Migration. https://displacement.iom.int/reports/pakistan-floods-dtm-situation-overview

[42] The Lancet. (2022). Pakistan's floods: A public health crisis in the making. The Lancet, 400(10363), 867. https://doi.org/10.1016/S0140-6736(22)01700-9