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ORIGINAL PAPER

Improving decision support system in identifying vulnerability rating and prioritizing the best interventions for sustainable watersheds in Pakistan, Nepal, and Sri Lanka

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Abstract: Quantification of watershed vulnerability rating and prioritization of the best watershed management intervention is always a challenge for multidisciplinary experts in developing consensus. Consequently, the lack of a decision support system (DSS) negatively affects the adoption of promising interventions leading to reduced watershed communities' resilience to climate change. Therefore, a DSS has been developed to integrate local multi-disciplinary knowledge in identifying the watershed vulnerability ratings and prioritizing the best site-specific watershed management interventions. The DSS developed was applied to selected watersheds using 25 local experts in Pakistan, Nepal, and Sri Lanka. Results showed that DSS is conveniently applicable and effective in developing consensus among multidisciplinary experts. The DSS recommended that the best interventions for the selected watersheds should primarily reduce the existing accelerated land and water degradation through engineering and biological actions. These actions may include controlling the rainwater run-off losses through appropriate harvesting systems and their subsequent efficient utilization for improving food security, climate change resilience and livelihood of vulnerable watershed communities. The DSS developed can be helpful in developing local adaptation plans and strengthening the policy support for promoting sustainable watersheds in Pakistan, Nepal, and Sri Lanka. However, the system needs further refinement through the incorporation of the design, specifications and costing of the interventions and making the data acquisition and analysis automatic using an online electronic system for quicker results and appropriate resource allocation for stimulated adoption.

Keywords: Watershed management, climate change, vulnerability rating, engineering and biological interventions, rainwater harvesting.

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Introduction

The degradation of natural resources due to destructive impacts of climate change like droughts with reduced water availability (Ahmad et al., 2023), floods and increasingly severe storms represent a potentially serious threat to sustainable agriculture in South Asia (Rafiq and Blaschke, 2012; Reddy et al., 2017). Therefore, there is exposure and vulnerability of the population that lives in this region to natural meteorological disasters (Liu et al., 2019; Mall et al., 2019; Abbas et al., 2023; Enu et al., 2023).

However, the existing traditional practices for mitigation of drought and flood risks in watersheds are not appropriate to cope with these disasters (Prabhakar and Shaw, 2008). Using remote sensing techniques, a significant impact of climate change on the livelihood of watersheds has been reported, especially in South Asia (Ashraf et al., 2011; Rafiq and Blaschke, 2012; Maqsoom et al., 2020). Therefore, skilled human resource development and improved knowledge of watershed management strategies are urgently needed for sustaining food production and improving livelihood in South Asia.

Numerous attempts using individual approaches have been made to address climate change, watershed vulnerability and community's resilience to climate change issues on a regional basis (Aftab et al., 2012; Alam et al., 2012; Akbar, 2013), but with a specific focus on a particular subject area. However, decision support guidelines are rare for the local multi-disciplinary professionals to collate their subject-specific knowledge regarding scrutinizing site-specific issues, developing local adaptation plans and prioritizing best-needed interventions on consensus. Generally, the resources are limited and there is a need to invest the available funds efficiently in the most demanding interventions through consensus with the support of local multidisciplinary stakeholders for more effective and sustainable outcomes.

Addressing these issues, this study is aimed to develop a decision support system (DSS) using local multidisciplinary knowledge in developing consensus, involving a long listing of suitable watershed management interventions according to the local climate change scenario, systematic identification of watershed vulnerability rating in quantifiable terms and then prioritising the best site-specific interventions for adoption. This kind of study is rare for identifying the watershed management vulnerability rating and best-watershed interventions in the selected areas.

Material and Methods

The study is focused on prioritizing the best interventions for a specific watershed in Pakistan, Nepal, and Sri Lanka. The majority of the watersheds in these countries are prone to degradation due to erosion, leaching and intensive agriculture. As a first step, the list of professionals from lined departments working in a specific watershed is collected through coordination with local lined departments, NGOs, and community organizations.

Each professional is asked to provide separate feedback regarding the local climate change scenarios, issues, options, interventions and way forward with respect to their specific subject area. An inventory of existing watershed management interventions established through ongoing government programs/subsidies, international funding, local communities or on an individual basis. Further available information from local, national and international reports, published articles, and print. electronic and social media are also collected. All this information is used in developing a long list of potential watershed management interventions for an area.

A systematic mechanism for identifying the watershed vulnerability rating and prioritizing the best watershed management interventions using a questionnaire developed for this purpose is followed (Table 1). Currently, the prioritization is done through conducting a joint meeting of stakeholders (professionals, community workers, and service providers) and their further sub-group formation for a good representation of individuals in a multi-disciplinary team. Each group fill out the questionnaire through consensus after a detailed group debate. A long list of recommended watershed interventions is prepared by each group followed by a group representative presentation for justification and addressing questions of other group members. A comprehensive long list of potential watershed management interventions is prepared for a watershed. The watershed management interventions from the long list are then prioritized and shortlisted through voting by the stakeholders purely on merit.

The above mechanism was applied on separate watersheds in Pakistan, Nepal, and Sri Lanka. To test and validate the decision support system (DSS), a total of twenty-five local experts working in the lined departments (soil conservation, on-farm water management, agriculture extension, research organizations, universities, national rural support programs, NGOs, etc.) of the three countries were selected and feedback was received regarding the site-specific issues, options and existing watershed management practices. A long list of potential watershed management interventions was developed for each country. Then a joint meeting was separately convened in each country through international funding. The professionals were initially updated on recent climate knowledge, climate change, details of the long-listed sustainable watershed management practices, climate resilience and food security issues by the prominent experts in respective countries. Then the participants were engaged more interactively for the application of the DSS and to effectively benefit from their multi-disciplinary local knowledge.

The professionals were divided into three groups for watershed vulnerability rating assessment and recommending the best watershed management practices using the DSS, per their local knowledge and expertise. Each group was given two to three hours for selecting a watershed, and finalizing their assessments using the DSS, which was followed by a short presentation by each group leader for sharing the outcome and to provide justification for their recommendations. Each presentation was followed by a question-and-answer session between groups to further refine the outcome. Each multi-disciplinary group successfully provided recommendations regarding the watershed vulnerability rating and prioritized interventions for selected watersheds.

The cumulative recommendations from three groups were used for developing a list of ten technologies for respective countries and using the number of occurrences of each technology in all groups as a criterion for sorting the priority of a particular technology. These technologies were further prioritized using voting by putting red, green and yellow color tags for indicating the best, better and good intervention by each professional for the respective country and region. Thus, the four most suitable best/innovative technologies were finalized for sites of the three countries. Important interventions for the three countries are listed for showing regional preferences and prospective mutual programs.

The data presented includes the list and details of recommended watershed interventions for the three countries. The long list of interventions is divided into headings and subheadings depending on the main features of the interventions to cope with a potential climate change risk. The questionnaire developed for identifying the watershed vulnerability rating and recommending the best intervention is also provided. The results of the step-by-step application of the DSS mechanism in three countries are presented in tabular form.

Table 1: Assessment sheet for evaluation of watershed management and risk vulnerability rating

Evaluator: ______________________________ Date: ______________________________
Farm/Field/Area Evaluated: ______________________________ Total Score: ______________________________

Risk rating	**Excellent**	**Good**	**Fair**	**Poor**	**Recommended Interventions**
Erosion potential	Minimal sediment movement Some sheets and rill erosion are evident Very few gullies or minimal furrow erosion	Some sediment movement Some sheet and rill erosion are evident, and very few gullies or minimal furrow erosion	Significant sediment movement Significant sheet and rill erosion Obvious gullies after storm events or significant erosion	Heavy sediment movement Severe erosion with topsoil eroded away Many gullies, critical erosion areas, or severe furrow erosion	
	10	6	3	0	
Runoff potential	Low: 80% or more ground cover Sandy soils Very flat to flat terrain (0-5% slope) Rainfall (< 203.2 mm) Even, gentile impact (scattered shower-type) of rainfall Proper rainwater harvesting	Moderate: 60% or more ground cover Loam soils Flat to gently flopping (0.5-2.0% slope) Rainfall (203.2-381.0 mm) Even, gentle to moderate intensity rainfall	Considerable: 30% or more ground cover Silty and clayey soils Gently to moderately sloping (2.0-5.0% slope). Rainfall (406.4-558.8 mm) Even intense rainfall	High: Little to no ground cover Clay soils Moderately sloping to steep (> 5.0%) Rainfall (> 558.8 mm) Intense uneven rainfall in seasons when soil is exposed	
	10	8	4	0	
Management systems on the whole watershed	Excellent management: Utilize all four soil health principles: keep it covered by residue and crop canopy, living root/eliminate fallow add cover crops, little to no tillage disturbance; crop diversity by using cover crops and diverse rotations	Good management: Most (80%) of the health planning principles	Fair management: About 50% of the soil health planning principles in place	Poor management: Few, if any, of the soil health planning principles are installed	
	9	7	3	0	

Table 1: (Continued)

Buffer zone	More than 60 m of dense vegetation between the field edge and water course/waterbody Un-grazed or dense grass-like plants	30 to 60 m of dense vegetation between the field edge and water course/water body Moderate grazing or moderate density grass-like plants	Less than 30 m of dense vegetables between the field edge and the water course/water body (no bank riparian vegetation)	Heavy grazing or cropping up to the water edge Minimal bank (riparian) vegetation	
	10	7	0	0	
Fertilizer management practices	Excellent 4R: Management or no fertilizer necessary Well-defined schedule as to frequency timing for inorganic or organic fertilizer depending on crop type, the height of growth, etc. Application of exactly the proper (recommended) amounts according to soil tests Pays close attention to weather forecasts; Never applies before a storm Fertilizer is injected or incorporated into the soil	Good 4R management: Mainly follows a schedule but sometimes missed the best timing for the maximum utilization by the crop Usually follows directions for proper dosages of fertilizer and has soil tested regularly; Follows weather forecasts but once in a while will risk applying when rain is forecast Fertilizer is mainly of the incorporated slow-release type. Occasionally uses soil test to base application rates	Average 4R management: Follows a schedule about half the time Application is based on convenience Tends to “over-fertilize by using more than the recommended dose Occasionally uses much of the application in a washout; More than half the fertilizer is applied to the surface	Minimal 4R management: Seldom follows a schedule Does not use a soil test to base application rates and fertilizer type; Applications without heed to weather forecasts Often loses most of the applied fertilizer in a washout; Applies usually too little sometimes too much Most of the fertilizer is surface applied without injection or incorporation	
	9	7	3	0	

Table 1: (Continued)

Potential for groundwater contamination (wellhead protection area)	Low: Slow to very slow percolation in heavy soils such as clays, silty clays or silty clay loams Water depth is greater than 60 m Wellhead has a 60 m buffer with no nutrients applied and is very well protected from flooding Backflow and protected from all potential hazards Wellhead is excluded from grazing and livestock protected	Moderated: Slow to moderate percolation in clay loams or silts Well depth is less than 30 m; Nutrients are applied within 2.5 m of the well or are not protected from flooding Grazing occurs adjacent to the well but the wellhead has some protection such as a cover, or other protection from livestock grazing	Considerable: Moderate to rapid percolation in silty loams, loams, or silts Well depth is less than 30 m; Nutrients are applied within 2.5 m of the well or are not protected from flooding Grazing occurs adjacent to the well but the wellhead has some protection such as a cover, or other protection from livestock grazing	High: Rapid percolation in coarse-textured sandy soils, subsoil sands, gravels, or shallow water tables Well depth is less than 1.25 m Nutrients applied next to well or grazing directly adjacent Unprotected wellhead opens to runoff. Flooding, grazing or opening to the air	
	9	6	4	0	
Irrigation management practices	Proper irrigation scheduling; Use of highly efficient irrigation systems (sprinkler and drip) Conveyance losses are minimal Minimum irrigation water losses Lined water courses	Partially lined water courses Moderate maintenance Furrow bed irrigation system Sandy clay soil Proper irrigation schedule Moderate irrigation losses	Vegetative canals Little maintenance About 50% of needy practices Traditional irrigation scheduling Seepage losses Non-uniform distribution	Earthen unlevelled canal bottom Poor management Few needed practices installed High irrigation losses Traditional irrigation scheduling No leaching management	
	10	7	3	0	
Add the individual rating score to get a total for the field			Total		
Circle the ranking for the site based on the total field score					
Ranking	**Excellent (56-67)**	**Good (33-55)**	**Fair (9-32)**	**Poor (8 or less)**	

Results

Evaluating watershed risk vulnerability rating

The assessment sheet developed for evaluating the watershed risk vulnerability rating and proposing recommended interventions is given in Table 1. One among the four choices in each row is selected for the best description of the existing conditions of the selected watershed. The proposed best intervention from the long list was selected for each risk, as described in detail below.

List of watershed management interventions

The results on the basis of feedback from local professionals, literature review and synthesis by the local and regional experts, the following long list of recommended watershed management interventions is prepared given below:

Field and buffer practices

Bed planting – growing crops on beds rather than flat ones. Plant wheat, maize, rice, oilseeds and vegetables on beds to improve irrigation efficiencies and yields;

Buffer planting (filter strips, field borders, etc.) – planting strips of grass or trees on the bottom edge of fields and/or around the edge of water bodies, drainage ditches or well heads to filter, and purify runoff;

Cover and green manure crops – use of cover crops between cropping periods to reduce runoff/erosion, provide nutrients, and improve soil health;

Contour farming – farming sloped land on the contour to reduce erosion, control water flow, and increase infiltration;

Critical area planting – plant perennial vegetation on highly erodible areas and slopes subject to excessive soil erosion and runoff;

Crop residue use – leave taller stubble or leave all crop residue in the field after harvest rather than removing it to return nutrients to the soil and to protect cultivated fields from erosion and runoff;

Crop rotation – diversify crop rotation to improve soil health, fertility, and control diseases;

Grasses and legumes – use of grasses and/or perennial legumes in crop rotation for livestock, forage, and grazing.

Mulching – applying residue to the soil surface to reduce evaporation, runoff losses, and soil erosion;

Riparian buffers/management – strip of perennial grasses and trees/grasses to filter sediment in runoff adjacent to streams;

Stubble burning replacement – eliminate burning of crop stubble/residue to protect soil, reduce air pollution, and save soil moisture;

Zero tillage/no-till – plant directly into previous crop residues with planting devices that only disturb the planting zone e.g., zero till planter.

Water/erosion control measures

Check dams – retention of water for irrigation use, reduce runoff, retain nutrients, pesticides and prevent sediments and other pollutants from reaching water courses;

Diversions – to divert runoff or irrigation water;

Grassed waterways – installed in concentrated flow areas subject to erosion by shaping and seeding to perennial grasses that reduce flow velocity and prevent erosion;

Gully farming – farming areas where sediments deposit directly above check dams that were formerly gullies. This practice stabilizes gullies and prevents sediments losses due to gullies;

Ponds – retention or detention of water for irrigation use, human use, fisheries or other purposes;

Pond sealing or lining – installing a fixed lining of impervious materials or treating the soil in a pond to reduce or prevent excessive water loss;

Sediment basin – a basin constructed to collect and store sediments from runoff water;

Terrace – an earth embankment, channel or a combination of ridge and channel constructed across a slope to control runoff.

Irrigation water management

Land grading/levelling – reshaping the surface of the land to improve surface drainage and/or irrigation water distribution;

Irrigation water conveyance – a pipeline or lined waterway constructed to prevent erosion and loss of water;

Drip irrigation – use drip irrigation to deliver small quantities of water more efficiently to irrigate crops and plants;

Irrigation water management – manage the rate, amount and timing of irrigation water applied to crops according to crop water requirements;

Micro catchments – fabricated or excavated catchments installed around the base of trees, vines, orchards, shrubs, or individual plants to prevent rainwater runoff to reduce irrigation water use, conserve rainwater in rootzone profile and more efficient watering system;

Solar-powered irrigation pumping – to reduce energy use and air pollution and efficiently utilize the irrigation water uniformly;

Sprinkler irrigation – use sprinkler irrigation for early germination and efficient use.

Drinking water treatment

Application setbacks – avoid application of fertilizers, manure, pesticides or other potential contaminants within designated buffer zone distance;

Water treatment – treat water for safe use of human and animal consumption;

Human access – eliminate entry of human sewage and pollutants to water bodies;

Human waste management – properly manage pollutants such as waste oil, paint, sewage, and other contaminants associated with dwellings;

Rooftop rainwater harvesting – collect rooftop rainwater runoff for irrigating crops, reducing runoff, kitchen gardening, and recharging aquifer;

Septic system – install proper septic tanks and management system;

Sewage treatment improvement – treat sewage with a lagoon, septic system, and leach field, improve sewage storage and eliminate untreated sewage entry to surface water;

Water storage improvement – reduce evaporation and improve drinking water storage;

Wellhead protection – establish a buffer area around the water well to avoid contamination from runoff, sediments, air or other sources of pollution.

Livestock grazing management

Fencing for livestock exclusion – exclude livestock from environmentally sensitive areas such as stream banks, water bodies, wellheads, erosion-prone areas and areas not intended for grazing, so that protection against damage can be ensured;

Prescribed grazing – proper grazing management to improve vegetative conditions and reduce soil erosion;

Trough or tank – locate watering facilities a reasonable distance from watercourses and disperse the facilities to encourage uniform grazing and to reduce livestock concentration, particularly near water courses.

Nutrients and manure management

Fertilizer – 4R (right fertilizer, right rate, right time, and right place) management;

Composting – properly compost manure, household, and other wastes for application to agricultural fields. Monitor compost temperature closely when the temperature reaches 150ºC for three consecutive days most pathogens will be eliminated;

Soil and water testing or plant analysis – testing soils or plants to determine plant fertilizer requirements to avoid over-fertilization and subsequent nutrient losses to runoff water. Test irrigation water for nutrient content;

Waste utilization – using farm yard manure and compost appropriately for fertilizer;
Waste storage structure – storage of animal and other organic agricultural wastes.

Salinity management

Leaching – leach excess salts with planned irrigation events;
Water testing – water testing for avoiding salinity build-up through better management;
Skimming well – salt level is closely monitored, while freshwater is skimmed off the surface by irrigation pumping to avoid mixing of freshwater with brackish water in the aquifer and provide freshwater for the intended use;
Salt tolerant crops/varieties – use salt-tolerant crops for more production in saline soils.

Prioritizing best watershed management interventions

The best watershed management interventions were prioritized using the DSS by each group, as results shown in Tables 2, 3, and 4 for Pakistan, Nepal, and Sri Lanka, respectively.

To further refine the prioritization process among the groups for general watersheds in the selected locality in each country, each participant was provided three colour tags for pasting on the listed technologies as per their preference in the following order; red tag for a best, green tag for a better and yellow tag for a good. The ten best technologies prioritized based on the frequency of occurrences and voting with three options among the three groups, as shown in in Tables 5, 6, and 7 for Pakistan, Nepal, and Sri Lanka, respectively. Thus, based on the information presented in the respective tables, the most effective top four technologies for the watersheds of the three countries were selected (Table 8).

Table 2: Prioritized best interventions for a selected watershed in Pakistan

Object		Group 1	Group 2	Group 3
Watershed name			Rawal watershed	
Group members number		7	7	7
Ranking		17 (Fair)	25 (Fair)	28 (Fair)
Prioritized technologies by the three groups	1	Grasses and legumes	Contouring	Check dams
	2	Critical area planting	Terracing	Terraces
	3	Riparian buffers	Forestation	Fencing for livestock
	4	Green manuring	Gully Plugging	Grasses and legumes
	5	Crop residue use	Check dams	Mulching
	6	Crop rotation	Reservoirs	Crop rotation
	7	Stubble retention	Residue retention	Soil and water testing
	8	Check dams	Awareness	rainwater harvesting
	9	Diversions	Irrigation management	Spring shed management
	10	Grassed waterways	Rainwater harvesting	Plant analysis

Table 3: Prioritized best interventions for selected watersheds in Nepal

Object		Group 1	Group 2	Group 3
Watershed name		Shivapuri	Malamchi	Rapti
Group members number		7	8	8
Ranking		30 (Fair)	21.5 (Fair)	21 (Fair)
Prioritized technologies by the three groups	1	Waste utilization	Check dams	Check dams with bioengineering
	2	Drip irrigation	Terrace/contour farming	Buffer planting
	3	Water conveyance	Critical area planting	Conservation ponds
	4	Ponds	Irrigation management	Inter-cropping/agro-forestry
	5	Mulching	Micro catchments	Mulching
	6	Fencing for livestock	Sewage treatment	Livestock grazing management
	7	Riparian management	Composting	Soil and water testing
	8	Check dams	Mulching/crop rotation	Micro catchment
	9	Terrace	Rainwater harvesting	Well-head protection
	10	Critical area planting	Salt tolerant crops	Grass water ways

Table 4: Prioritized best interventions for selected watersheds in Sri Lanka

Object		Group 1	Group 2	Group 3
Watershed name		Mahaweli	Thirapani	Upper Kothmale
Group members number		7	8	8
Ranking		16 (Fair)	21 (Fair)	22 (Fair)
Prioritized technologies by the three groups	1	Critical area planting	Irrigation management	Ground cover crop
	2	Contour farming	Solar powered pumping	Minimum tillage
	3	Check dams	Soil and water testing	Check dams
	4	Terracing	Terrace/contour/bed planting	Soil conservation
	5	Irrigation management	Land levelling	Mulching
	6	Raised bed planting	Crop rotation	Organic manure use
	7	Micro catchment	Wellhead protection	Reducing pesticides use
	8	Buffer planting	Mulching/residue retention	Waste management
	9	Soil and plant testing	Buffer planting	Fertilizer management
	10	Waste management	Waste utilization	Irrigation management

Table 5: Most effective interventions prioritized for watersheds in Pakistan

Number	Prioritized technologies	Category-wise number of votes			
		Best	Better	Good	Total
1	Check dams and structures	7	2	2	11
2	Forestation	4	3	4	11
3	Rainwater harvesting	4	3	1	8
4	Highly efficient irrigation	0	3	4	7
5	Terrace farming	2	2	1	5
6	Crop rotations	0	3	2	5
7	Grasses and legumes	0	1	2	3
8	Crop residue management	0	0	2	2
9	Mulching	1	0	0	1
10	Soil and water testing	0	1	0	1

Table 6: Most effective interventions prioritized for watersheds in Nepal

Number	Prioritized technologies	Category-wise number of votes			
		Best	Better	Good	Total
1	Check dams/bioengineering	11	3	1	15
2	Grasses and cropping management	3	2	4	9
3	Conservation pond	3	1	4	8
4	Irrigation management	0	7	0	7
5	Fertilizer management	0	0	6	6
6	Critical area planting	2	2	0	4
7	Human waste management	0	2	2	4
8	Terracing	0	2	1	3
9	Micro catchment	0	0	1	1
10	Mulching	0	0	0	0

Table 7: Most effective interventions prioritized for watersheds in Sri Lanka

Number	Prioritized technologies	Category-wise number of votes			
		Best	Better	Good	Total
1	Irrigation management	9	1	3	13
2	Critical area planting	3	2	7	12
3	Waste management/utilization	0	5	3	8
4	Micro catchment management	3	2	2	7
5	Soil, water and plant testing	0	4	2	6
6	Rainwater harvesting	2	1	1	4
7	Crop rotation	1	1	1	3
8	Drinking water treatment	1	0	1	2
9	Buffer planting	0	1	1	2
10	Terrace/contour/bed planting	0	0	1	1

Table 8: Top four technologies for selected watersheds of the three countries

Technology	Pakistan	Nepal	Sri Lanka
1	Check dams and structures	Check dams/bioengineering	Irrigation management
2	Forestation	Grasses and cropping	Critical area planting
3	Rainwater harvesting	Conservation pond	Waste management
4	Highly efficient irrigation	Irrigation management	Micro catchment management

Discussion

The technique developed for evaluating the climate change risk vulnerability rating and prioritizing the best watershed intervention was successfully tested and the local experts working in lined departments of all three countries showed convenience in their application and a keen interest in their use. The dispersed knowledge of the multi-disciplinary local experts was successfully integrated into prioritizing the site-specific watershed management interventions and their shortlisting according to local conditions through consensus. The results of the study for all three countries recommended nature-based solutions for ensuring reliable water supply and eliminating climate change-induced risks, which conform to the recommendations of Roder et al. (2021) for the Himalayan region.

The use of the decision support system (DSS) for Pakistan revealed that the selected watersheds are facing land degradation due to accelerated erosion and runoff losses, thus causing reduced water availability issues, which conform to other local studies (Ullah et al., 2018; Shrestha et al., 2020). Therefore, erosion control, forestation, rainwater harvesting, and efficient water use were prioritized for mitigating the climate change impacts.

Nepal mostly hosts hilly, unlevelled and sloppy watersheds, extremely vulnerable to climate change and anthropogenic risks (Adhikari et al., 2020). The DSS revealed the biggest challenge for the selected watersheds in Nepal is the accelerated land erosion, reduced ground cover, increased run-off losses, and inefficient use of the declining available water, which also conform to local studies (Chapagain et al., 2019; Lama et al., 2019; Adhikari et al., 2021). Thus, erosion control structures, grasses, ponds, and improved irrigation management were recommended, which also conforms to the recommendation of Hussain et al., 2018). Sri Lanka is surrounded by sea and receives sufficient rainfall, thus irrigation management is generally overlooked, while the dense land cover is also declining rapidly (Jayasekara et al., 2018). The DSS revealed better irrigation management for the declining ground cover, critical areas protection, waste water management and rainwater harvesting as the main interventions for the selected watersheds, which also conforms to other local studies (Komolafe et al., 2018; Wagenaar et al., 2019). Thus, the systematic technique of evaluating the watershed vulnerability rating and mechanism for longlisting and shortlisting of suitable interventions and prioritization mechanism developed through the DSS was very helpful and conveniently applicable. Limited available resource allocation can be optimized for spending on much-needed interventions through the consensus of stakeholders, which can be helpful in developing local adaptation plans and promoting best interventions for sustainable watershed management.

Conclusions

The watersheds in Pakistan, Nepal, and Sri Lanka are extremely vulnerable to climate change. The multi-disciplinary knowledge of local experts is not effectively contributing to the adoption of the best site-specific watershed management interventions due to lack of decision support system, thus leading to the misuse of limited available resources and degradation of watersheds.

The decision support system developed in this study helps to integrate the local knowledge of multi-disciplinary local experts in quantifying climate change vulnerability ratings of watersheds and prioritizing best site-specific interventions, which may be helpful in developing local adaptation strategies for climate change-prone watersheds.

The application of the decision support system in Pakistan, Nepal, and Sri Lanka revealed that the best watershed management interventions for the selected watersheds should reduce the accelerated land and water degradation through engineering and biological measures, conserve rainwater through rainwater harvesting and efficiently utilize the harvested rainwater through high-efficiency irrigation systems for improved livelihood and food security of watershed communities.

The decision support system needs further refinement by making data acquisition and their analysis electronically using an online system for quickly identifying the watershed vulnerability rating and prioritizing the best-watershed interventions at no significant cost. Design, specification and costing of interventions should also be integrated into the decision support systems for supporting policymakers in resource allocations, quantifying the interventions and stimulating adoptions.

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