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SWAT Based Prioritization of Sub-watersheds in Pohru Watershed of Jhelum Basin, Northwestern Himalayas

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ABSTRACT

SWAT "Soil and Water Assessment Tool" model has been extensively utilized for the prioritization of watersheds / sub-watershed and to estimate sediment yield index. Arc-SWAT, an Arc-GIS extension and interface for SWAT has been employed using Arc-GIS10.2 software. Climate data (temperature and precipitation) for a ten-year time period i.e., 2006-2016 of weather station in vicinity of the study area, Land use/Land cover map (IRS LISS III P6 of 2016), and Soil map derived through "National Bureau of Soil Survey and Land Use Planning of India" are the main datasets that have been utilized to extract the necessary input parameters for SWAT model. ASTER-GDEM has been used to delineate watershed outlines, generating sub-watersheds and slope map. A total of 41 sub-watersheds are delineated by selecting the appropriate threshold. Based on the post-processing, 6 sub-watersheds were placed in the very high priority category, 5 in high priority category, 12 in medium priority category, and 18 sub-watersheds in low priority category. Sub-watersheds which come under high priority category (i.e., 1, 2, 8, 10, 17 and 38) and high category (7, 15, 24, 31, and 35) are recommended for adopting on immediate basis for best soil loss management planning and sustainable agro-horticultural activities.

Key words: Sediment yield index, Watershed prioritization, SWAT model, Pohru watershed, Jhelum basin, Northwestern Himalayas

Land and water resources management on watershed basis becomes of paramount importance in context of the ongoing global change that is affecting these resources both quantitatively and qualitatively, particularly in the mountain regions. Watershed is a distinctive combination of climate, hydrology, soils, geology/hydrogeology, vegetation, and the community of human beings [17], [22]. Watershed approach has been progressively applied in various developmental programmes like soil, flood control, water resource conservation, river valley projects, resource dynamics and land reclamation etc. Watershed management practices coupled with amount and intensity of precipitation control the sediment yield as well as water produced in a watershed [55]. Sedimentation is an outcome of the land erosion in its catchment area. Estimation of sedimentation in reservoirs is an important part of the basic data/information which is required for any of the reservoir operation and management [6]. Data pertaining to sedimentation process would assist in prioritizing the areas within the watershed and subsequently ensures remedial measures that should be taken in advance in order for the proper planning, management and optimum utilization of reservoir operation. The constant and complex process of sediment deposition in a reservoir largely affects the reservoir useful life. Sediment yield estimation in a reservoir is essential for the affective planning and management of reservoir and river basin [33]. Therefore, sediment yield estimates are required for various studies pertaining to river morphology, reservoir sedimentation and planning water and soil protection/conservation measures [12], [33]. Identification of the areas which are problematic at micro level is considered to be a proper approach in terms of soil and land conservation measures [23]. In fact, starting management at most critical sub-watershed is always a better approach, thus makes it necessary to carry out prioritization of sub-watersheds as per order by which they need to be taken up for treatment for soil conservation measures [20]. The conventional methods make it a deadening and time-consuming activity to reach to the reliable estimates [21]. This makes the runoff modeling, sediment yield and soil erosion indispensable for sustainable developments of watershed. Distributed hydrological models which are physically based have been extensively utilized to model water resource systems which are complex in nature. They are also being used for modeling the of impact changing climate and landuse/landcover on water resources in different rivers and catchments during the past 10 to 20 years [29], [10]. Also, the basics of sustainable development

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are to maintain the fragile balance between productivity functions and conservation practices through monitoring and identifying the problem areas without affecting the precarious environmental conditions [40]. Moreover, the estimation of the amount of sediment and pollutants transported downstream brings out the essentiality of knowledge needed for sediment yield [54]. SWAT model has wide range of application in hydrological modeling and prioritization of watersheds as employed in various studies by numerous researchers such as [28], [46], [42], [52], [11]. This model (SWAT) has been frequently used to estimate simulations of sediment yield, surface runoff and total phosphorus losses from different watersheds/catchments at various locations, with conditions varying in terms of management practices [37], [48], [43], [32]. Patil and Shetkar in 2016 employed an Analytical Method to analyze the Sediment deposition of reservoir. The derived results from this method showed 8.82% error with respect to the actual measurements. SWAT model coupled with Remote Sensing and GIS was also used in kaya Gauged watershed of Northern Morocco to assess the sediment yield by [9]. [14] Predicted sediment yield in Western United States. [25], employed SWAT Model in Gorganrood Watershed of Iran to determine Sediment Yield, Surface Runoff, and Loss of Nitrates. Using SWAT model similar work was carried out at watershed level at watershed level by [3], [1], [23]. [51] in 2012 carried out work on watershed prioritization and sediment yield estimation using the combined approaches of remote sensing and GIS.

MATERIALS AND METHODS

The Study region, situated in North-western part of Kashmir Valley is covered between the geographic coordinates of 34°15´ and 34°42´N Latitudes and 73°54´ and 74°42´E Longitudes [55], [20], [22]. The study area is an oval-shaped valley with a an area of 1, 83,474 ha (Fig 1). The rock formations process underlying the Pohru watershed is ranging from Cambrian to Quaternary ages. Physiographically, the area can be broadly divided into three major landscapes namely Mountains, Karewas, and Floodplains. The soils of the Pohru catchment belongs to the groups of the alluvial soils, brown forest soils, and lacustrine (Karewa) soils. The soils classify as Orthents, Aquents, Fluvents, Ochrepts, Udalfs and Udolls.

River Pohru, the main stream flowing through study area, is also the major tributary of River Jhelum in northern part of Kashmir Valley. Mountain ranges, rising up to an altitude of about 4500 m asl, occupies northern and western part of the study region. The area is bounded on the northern and northwestern sides by the main water-parting ridge between Kishenganga and Jhelum basin, the eastern boundary is marked by Wular Lake while on southern side it is bounded by small ridges separating south-flowing tributaries of Jhelum and east flowing tributaries of Pohru. It has Temperate cum Mediterranean type of climate with average temperatures (T_{min} and T_{max}) varying between (–5°C) to (32°C) and receives an average annual precipitation (Rain and Snow) of about 869 mm [11]. Seasonal and annual temperatures in the study area have witnessed increasing trends during the recent times [19], [49], [50] in response to the changing global surface air temperature. In future, further increase in temperatures are likely to be expected which may affect the soil erosion and sediment redistribution up to greater extent [36], [47]. This further increases the ambit of understanding the nature and magnitude of sediment yield for prioritization of the watersheds in mountainous areas like in Kashmir Valley.

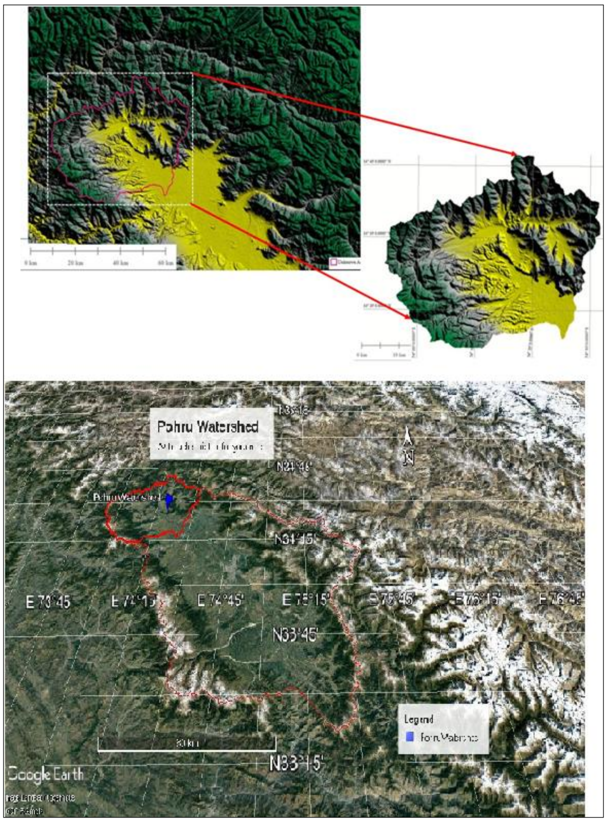

Fig 1 Study area location map
Source: ASTER DEM and Google Earth Image

The ASTER-GDEM "Advanced Spaceborne Thermal Emission and Reflection Radiometer, Global Digital Elevation Model having spatial resolution of 30-meter was downloaded using Global Mapper 15 interface. This DEM was loaded into Arc-Map 10.2 GIS Interface and processed for the watershed boundary delineation of Pohru watershed. The watershed was delineated by first generating the stream network and then selecting the outlet of the Pohru River, the trunk stream in this watershed. The threshold of (3000 ha) was given and subsequently 41 sub-watersheds were generated.

SWAT uses parameters like soil, land use, and slope, as well as their threshold inputs, to determine the degree of spatial information. Slope map was prepared from ASTER GDEM in ARCGIS10.2. The LULC (landuse/landcover) map was prepared from Resourcesat-1 (IRS P6) LISS III of 2016. Supervised classification was run in ArcGIS 10.2 to generate the total of 9 land use classes which were further reclassified into SWAT land cover/ plant type. Soil map of study region was digitized from the soil map which is prepared by "National Bureau of Soil Survey and Land Use Planning of India". Six soil classes were identified and named as per the SWAT requirements. Sediment Yield was estimated for each of the 41sub-watersheds, which were subsequently categorized into four classes (Very high, High, Medium and Low) on basis of their weightage value. Observed sediment yield of the years 2009 and 2010 was used for the purpose of Model calibration. Moreover, monthly runoff/discharge data of the years, 2011, 2012 and 2013 was used to carry out the validation of the model. The overall data processing steps are mentioned in (Fig 2).

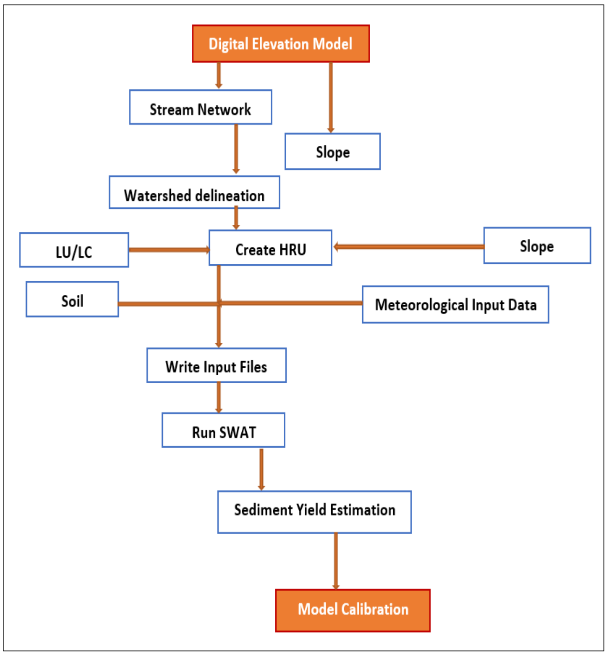

Fig 2 Workflow of methodology

A brief overview of the SWAT model

One of the most important aspects of water resource planning and management programmes is understanding hydrological processes and developing appropriate models. For the evaluation of water quantity and quality, watershed-based hydrologic simulation models are likely to be used. Various researchers have proposed a variety of interconnected physically-based distributed models, with SWAT being one of the most promising and computationally efficient models among them [15], [4], [30].

The Soil and Water Assessment Tool (SWAT) is a semi-physical, semi-distributed model developed by the Agricultural Research Service and Texas A&M University in the United States. The model is based on daily data and allows for the interconnection of various physical processes that take place in a watershed using a GIS environment [5], [4]. Arc SWAT 2012, has been revised as the most current edition of SWAT and extension of ArcGIS 10.x [53]. This interface simplifies data entry, input file construction, and parameter editing while allowing spatial parameters to be easily viewed in the ArcGIS context.

SWAT was created to forecast the effect of land management activities on water, sediment, and forage development over long periods of time in vast complex ungauged watersheds with varying soils, land use, and management conditions [4]. The model is built around basic action components like hydrology, climate, nutrients, sediments and agricultural management, and it can be linked to GIS software [31]. The SWAT creates an operating sequence that includes heating, sensitivity analysis, model parameter calibration, validation, and simulation of potential scenarios [35].

SWAT has proven to be effective for land-use change assessments, and it has spawned a growing number of research projects. SWAT has also been widely validated for stream-flow and sediment loads throughout the United States [45]. [8], [10], [2[, [39] have used SWAT model at watershed level studies. Since SWAT was generated in the early 1990s, the base for the model was groundwater loading effect on the management of agricultural systems. Its capabilities have been reviewed and expanded on a regular basis. The model has become progressively more popular in addressing anthropogenic challenges in diverse climatic, physiographic and socio-economic setting. A watershed is subdivided into several sub-watersheds in SWAT, which can then be further subdivided into hydrologic response units (HRUs) with similar land use, management, and soil characteristics [30].

RESULTS AND DISCUSSION

Sediment yields from soil erosion and runoff are becoming a major problem in mountainous areas, particularly in the Pohru catchment. In spite of the complications of the processes that has affected the sediment yield in the present watershed, this study shows that physically based models, especially SWAT model, can accurately predict basin scale suspended sediment yield. Despite the complexity of processes influencing sediment yield in this watershed, this research demonstrates that physically based models, specifically the SWAT model, can reasonably estimate suspended sediment yields at a basin scale. To improve the accuracy of the model performance, thorough sensitivity analysis, calibration, and validation should be used. In SWAT model watersheds are divided into sub-basins, which are then further divided into HRUs based on Soil, slope and Landuse. Each sub-basin or watershed contained the flow paths, slope, channel and boundary needed for routing the flow as well as the sediment and nutrient loads, all of which are computed using the input DEM, whose grid size has a significant impact on the flow and modelling nutrient load through various topographic attributes [13].

The area Pohru watershed has been divided into 41 sub-watersheds/catchments (Fig 3) and were numbered from 01 to 41 accordingly. The Sediment Yield Index (SYI) pertaining to all 41 sub-watersheds of Pohru catchment were estimated. The sub-watersheds were arranged with respect to the decreasing order of their SYI and graded into four categories as Very High, High, Medium, and Low, based on the SYI range as given in (Table 1).

Table 1 Priority categories based on sediment yield index

Priority category	Sediment Yield Index Range (Thousand Tonnes/ha.)	Category wise no. of sub-watersheds	Category wise distribution of sub-watersheds
Very high	Above 80	6	1, 2, 8, 10, 17, 38
High	40-79.9	5	7, 15, 24 31, 35
Medium	10-39.9	12	21,22,25,28, 29,30,33,34,36,39,40,41
Low	Below 10	18	3, 4,5,6,9,11,12, 13,14,16,18,19,20, 23,26,27,32,37

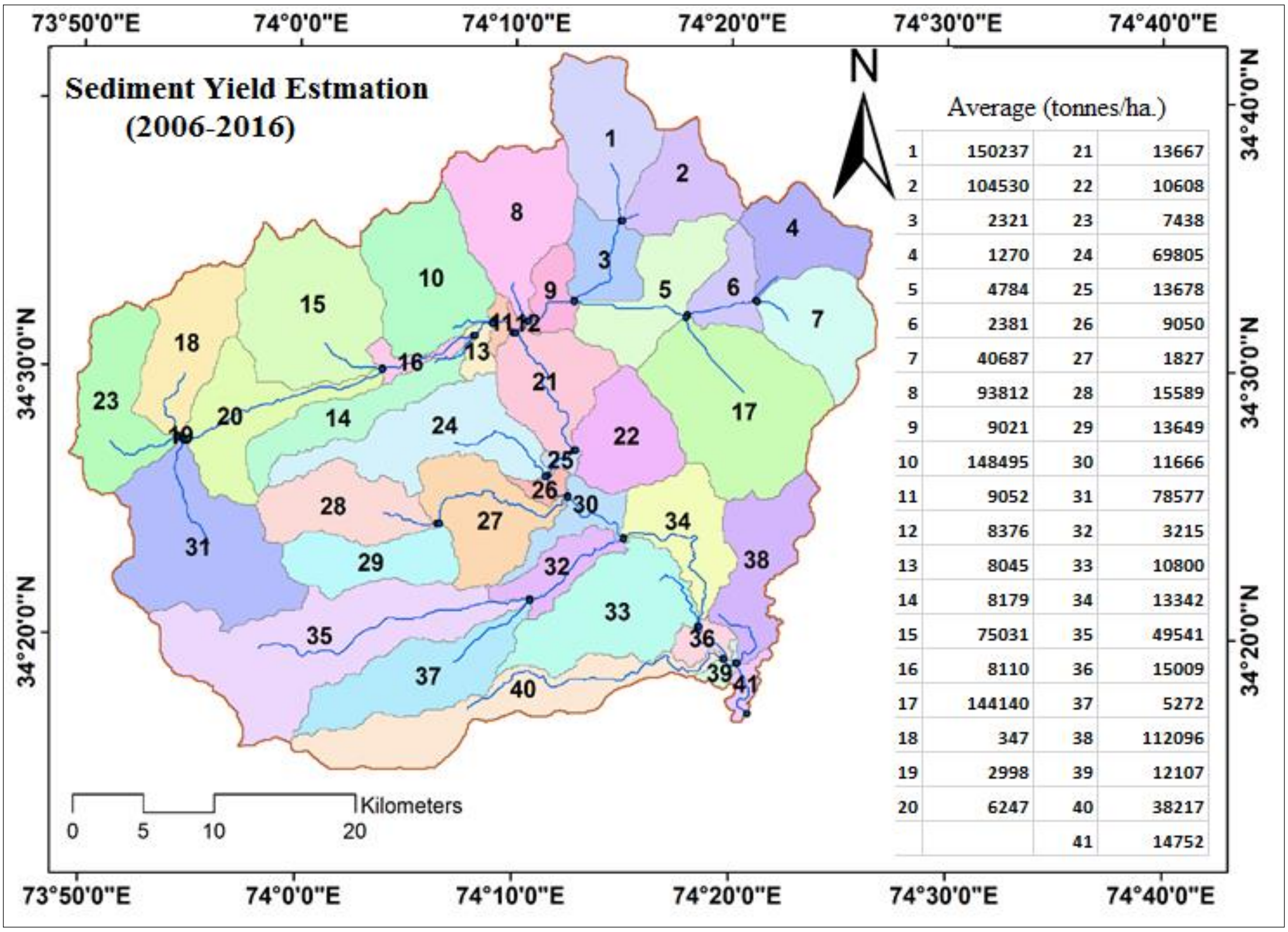

Fig 3 Sub-watershed sediment yield index map

The (Fig 3) reveals the sub-watershed index map with their sediment yield estimation for each of the sub watershed. The number and size of a watershed and sub-watersheds are based on the threshold value. In the present study, the minimum threshold area was taken to be 3000 ha which formed a total of 41 sub-watersheds and were numbered accordingly from 1 to 41. Once the watershed and sub-watersheds boundaries are delineated, all the geometric parameters of each sub-watersheds and stream reaches were calculated and stored as vector themes (.shp format). The sediment yield for each of the sub-watershed were estimated from the year 2006 to 2016. The figure 3 also reveals that the Sediment yields in some of the larger tributaries to the Pohru river is relatively large, most of the sediment in the study area appears to be generated from within the main river i.e. Pohru River itself. The sub-watershed no. 41 which covers the areas of Doabgah and its adjacent areas near Sopore town of Baramullah District has the largest sediment yield of all the tributaries assessed contributing its sediment load to Jhelum River. The high sediment yield suggests high erosion in the catchment while as Low sediment yield also suggests less erosion in the catchment areas and healthy land use/cover scenario. The complex interactions between various geomorphic processes such as sheet erosion, splash erosion, gully erosion, rill erosion, bank erosion, and mass movements result in basin scale sediment production [24]. From the last few decades scientists have received serious attention to the studies pertaining to the field in the high mountain catchments [18]. Soil erosion impacts in different ways such as loss of fertile soil [16] silting of reservoirs [38], increased flood risk [7] and debris flow events [27].

For all of the 41 sub-watersheds, the average sediment yield from the year 2006-2016 tonnes/ ha. were estimated. Based on their sediment yield estimation, each of the sub-watershed were placed from high to low categories corresponding to their respective sediment yield index values. Out of total 41 sub-watersheds, 6 sub-watersheds i.e., 1, 2, 8, 10, 17 and 38 are placed in the very high priority category, A total of 5 sub-watersheds i.e., 7, 15, 24, 31 and 35 were placed under high category of prioritization, 12 in medium, and 18 sub-watersheds are placed in the low category of prioritization as given in (Fig 4, Table 2). The study also reveals that the average sediment yield from the year 2006 to 2016 was recorded high in the year of 2014 followed by 2015. Monthly based sediment yield from 2006 to 2016 was recorded high in the month of February while as Nov. recorded the lowest sediment yield estimation.

This study has been conducted with the view to identify the areas of critical concern from sustainable management of the Pohru watershed that shows heterogeneousness characteristic with respect to land use/land cover, soil characteristics and hydrology. These resources are depleting in the area and require immediate attention from the planners. It is imperative to prioritize the plan of activities for achieving fruitful results. This resource depletion is visible in all the catchments of the study region. The forest cover has shown considerable loss in the study area led to increased sediment yield and enhanced soil erosion at different rates in different sub-watersheds. It is therefore realized to carry out prioritization of the sub-watersheds based on the estimation of sediment yield for soil and water conservation measures. The sub-watersheds with more susceptibility to erosion hazards are recommended for treatment on priority basis.

This priority map or severity shows that to overcome the problem of soil loss in the catchment and priority for immediate action should be given first for the watersheds which are under very high and high, and then to moderate and slight respectively. Similarly, it can be used to overcome the problem of soil loss at a point and siltation problem in the reservoir through the proper soil and water conservation planning based on the priority categories.

Table 2 Sediment yield index (SYI) of sub-watersheds

Sub-watershed Id. No	Average sediment yield (tonnes/ha)	Sub-watershed priority	Sub-watershed Id. No	Average sediment yield (tonnes/ha)	Sub-watershed priority
1	150237	1	22	10608	23
2	104530	5	23	7438	31
3	2321	38	24	69805	9
4	1270	40	25	13678	17
5	4784	34	26	9050	25
6	2381	37	27	1827	39
7	40687	11	28	15589	13
8	93812	6	29	13649	18
9	9021	27	30	11666	21
10	148495	2	31	78577	7
11	9052	25	32	3215	35
12	8376	28	33	10800	22
13	8045	30	34	13342	19
14	8179	28	35	49541	10
15	75031	8	36	15009	14
16	8110	29	37	5272	33
17	144140	3	38	112096	4
18	347	41	39	12107	20
19	2998	36	40	38217	12
20	6247	32	41	14752	15
21	13667	17			

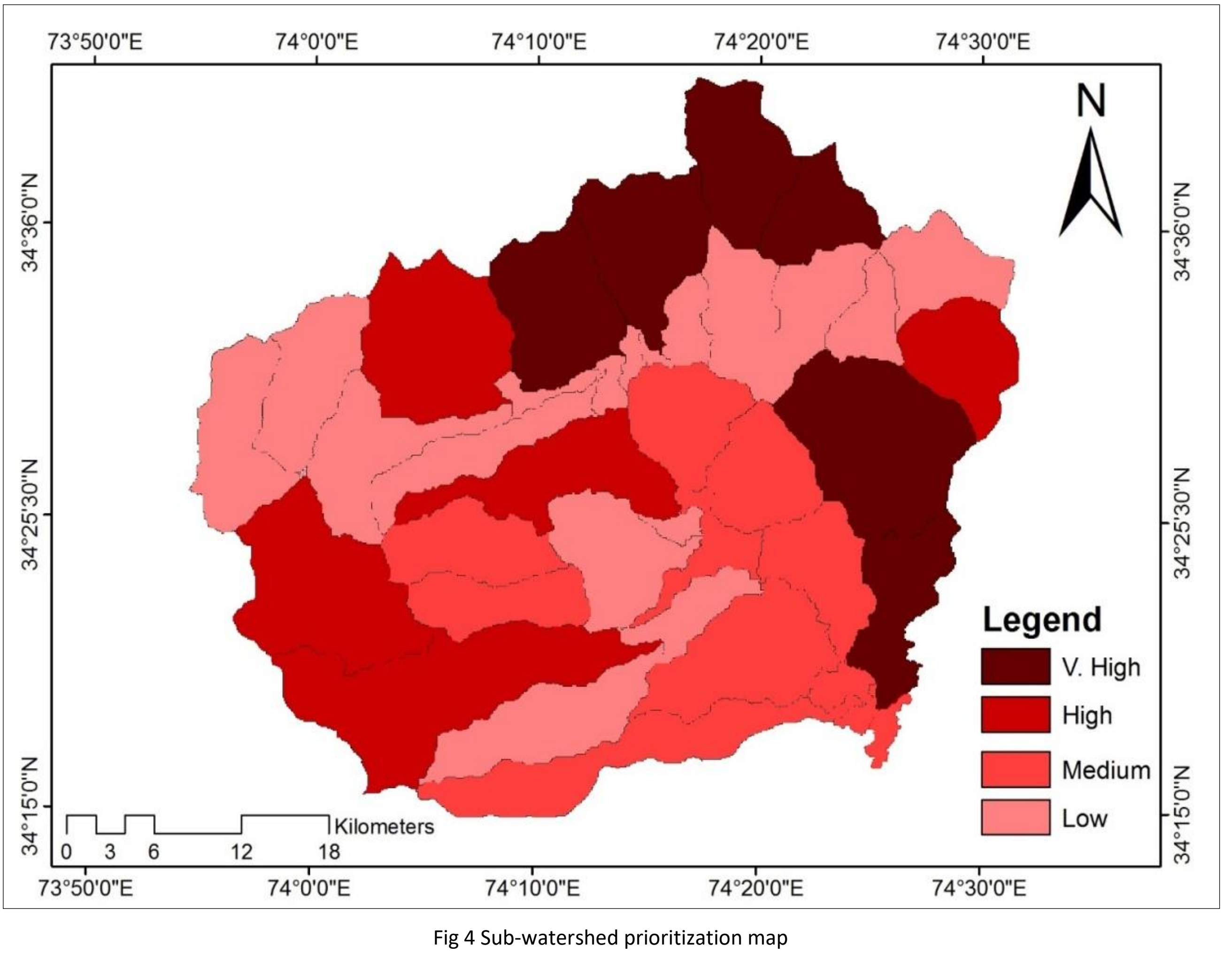

Fig 4 Sub-watershed prioritization map

CONCLUSION

Sediment Yield estimation was carried out from (2006-2016) for all of the sub-watersheds in Pohru watershed of Jhelum basin. 6 sub-watersheds were placed in very high priority category, 5 in high priority category, 12 in medium priority category, and 18 sub-watersheds in low priority category. The sub-watersheds 1, 2, 8, 10, 17 and 38 placed in the very high priority category and sub-watersheds 7, 15, 24, 31 and 35 placed under high category are recommended for developing the best soil loss management planning and sustainable agro-horticultural activities. Being a mountainous region, the study area has high to a very high rate of sediment yield. A high sediment yield indicates high erosion in the watershed/catchment, while a low sediment yield indicates less erosion and a balanced land use/cover scenario in the catchment. The various land us land cover dynamics and other meteorological factors plays a decisive role in shaping the sediment yield estimation of a watershed. The decrease in the vegetation cover of an area can be hazardous in terms of sediment yield and similarly the increase in the barren land, pastures, built up area, tillage area can prove disastrous for the sediment yield in any area. The more area under vegetation especially forests will drastically bring down the sediment yield because of binding of soil and loose particles associated with it. While as, the increase in the barren area, built up area, tillage area will greatly enhance the amount and rate of sediment going out of the watershed/area. The rate of sediment yield in the study area falls mostly under moderate to high category Thus, the catchment is subjected to moderate to high soil erosion, and has the high effect on water storage capacity. This suggests that the watershed possesses moderate to high topography where soil erosion is a serious threat. The result of the study clearly reveals that the watershed is prone to soil erosion and associated problems and requires regular monitoring from the planners and decision makers for making it better in terms of land and water conservation. These problems need to be tackled out on the priority basis through adaptation of both biological as well as engineering measures. This research study can be used as suitable basis for preparing any soil management and conservation planning in the study area.

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