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Watershed Prioritization and Water Conservation Site Selection for Nayagram block of Jhargram District, West Bengal

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Abstract: To meet the demand of food and water for exploitation of water resource is going on incautiously at several parts of the country. For sustainable crop yield and water harvesting land and water resource conservation is very much essential. Without proper replenish of aquifers along with natural environments socio economic condition of a society may face the challenge of extreme degradation. The selected study area, Nayagram block is fallen under poor water resource and high soil erosion zone. For the development of land and water resources of the area watershed management is found to be an idle option which is presently active in only 97 Km ^{2} (19.36 %) areas. To get more area under the control of watershed management project present study has conducted watershed prioritization through GIS study by dividing the area into 37 sub watersheds. For deriving the morphometric information of each sub watershed Digital Elevation Model (DEM) have been used. Prioritization was performed as per rank method by integrating several morphometric parameters of watersheds into account. As per study 7 sub watersheds have been found as prioritized sub watershed which will put additional 75.11 Km ^{2} new areas under management. For the management of 7 vulnerable watersheds conservation site was selected by considering the various physical aspects like LULC, soil, slope and stream order.

Key words: Watershed, Prioritization, DEM, Water conservation, Morphometric

1. INTRODUCTION

Water is considered as the most valuable natural resources in the world. Among the different sources of water amount of usable water is very low and most of it exploited from different sub surface aquifers and water bodies containing sweet waters. The sweet water is used in many domestic as well as economic purposes. Though water resource is a flow resource yet immense exploitation has put serious threat over its availability. Across the world 844 million people every day face the challenges of collecting drinking water (WHO, 2017) that is enough to narrate the significance of water related problems. With an average annual rainfall of 1,170 millimetres alms quarter amount of Indians regularly face the challenges of severe droughts. Due to very poor rain water harvesting structures the nation as managed only as it manages to store only 6% of its annual rainfall or 253 billion cubic metres (Integrated hydrological data book, 2015).

The western part of West Bengal generally possesses poor water resources due to lateritic hard cap, permeable soil and poor quality of aquifers. Nayagram block of Jhargram district is one of such dry area of the region which gets attention of scientist long ago (Biswas et al., 2007). In every summer an acute water crisis arises in the area causing the suffering of dwellers. However to improve the drinking water distribution the central government project, Swajaldhara has started to operating with an assurance of minimum per head supply of 40 litre of water (Ministry of Water Resources, GOI, 2002) as mentioned by Roy (2018). Such over exploitation of ground water at large scale without proper replenish may lead to extreme degradation of water resources along with its resultant negative impacts on socio economic condition. In order to increase the sustainability of water resource watershed program can be used with good impacts (Mehra & Rajeshwari, 2012). Watershed is a hydrological unit which is drained by several streams having a common outlet. It has a catchment area, common area and discharge area (Jain, 2004). Wani & Garg (2008) prescribed the essential role of watershed management in controlling land, water, food and livelihood system.

As per West Bengal State Watershed Development Agency (WBSWDA) report 2018 the block has two watershed in operation, i.e. Shitalpur and Gobindapur covering an area of 50 Km^2 and 47 Km^2 respectively running from 2011-12. Both the management program is running under the Drought Prone Area Program (DPAP). More than 100 census villages have been covered by this two watershed projects which is divided into 4 micro sheds each. A total of 706 lakh Rs and 655 lakh Rs have been sanctioned for the development of above mentioned projects. However the total area of Nayagram block is 501 Km^2 but of which so far 97 km^2 is only under watershed projects. As per need of the hour many micro watersheds are yet to be managed to develop the land and water resource.

Not all the sub watersheds can be managed at time so prioritization of watersheds is essential for ranking the watershed as per morphometric vulnerability. Morpohometry is the measurement and mathematical analysis of the configuration of the Earth’s surface, shape and dimensions of its landforms (Clarke, 1966). Modern RS and GIS based study have enabled to precisely delineate the sub watershed (Meshram & Sharma, 2017) along with vast amount of generated morphometric data bases (Singh et al. 2003; Pandey et al. 2011). Based on the morphometric details of each sub watershed prioritization can be done very easily as suggested in many literatures (Pandey et al. 2004; Durbude & Venkatesh 2004). Therefore the study has put focus to precisely delineate the sub watersheds as well to categorize them as their priority score depending on land water vulnerability. Management of watershed is very essential for proper water resource development (Jankar et al. 213). As per local knowledge and outcome of the several physical aspects like, drainage network, LULC, soil and slope of the area the study has suggested some water recharge structures (Pandey et al. 2011).

Study area

Nayagram block under Jhargram district of West Bengal is situated in the western fringe of Chotanagpur plateau (Figure 1). It has a geographical area of 501.44 km^2 bounded by 22 º 44 / N to 22 º 74 / N latitude and 88 º 08 / E to 88 º 13 / E longitude. The area falls under the historic Jangalmahal territory which is significantly familiar for abundance of tropical forest and tribal association. More than 15 % of the total area of the block is under dense forest dominated by Sal tree. The selected study area has a total population of 1, 42,199 among which around 40 % are tribal population (Census of India, 2011).

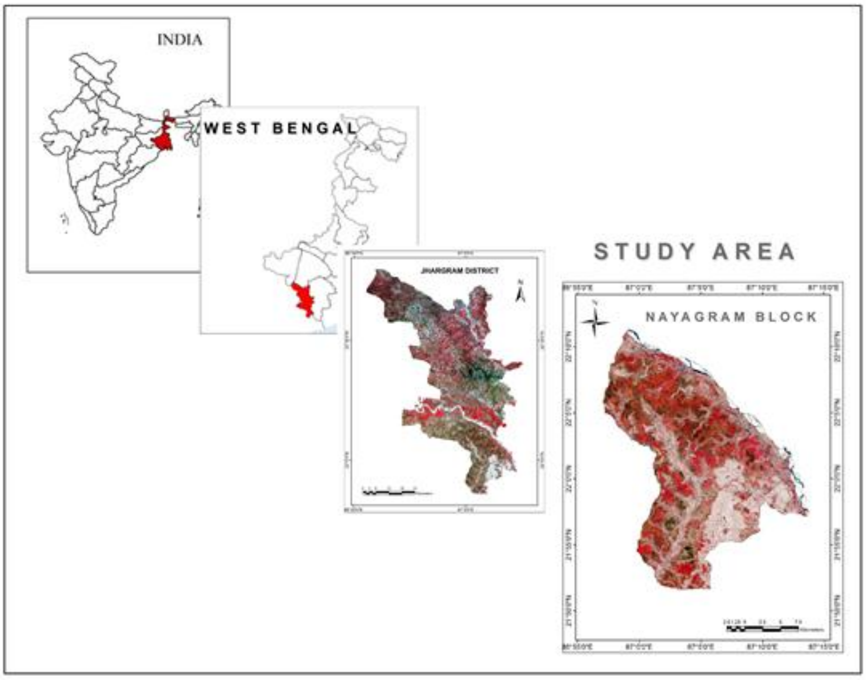

Figure 1: Location of study area

As per physical set up the area the area is mainly consist of deep to moderate buried pediments with Laterite capping at many places. Elevation of the study area has been found within a range around 117 m to 11 m from Mean Sea Kevel (MSL). The block receives an annual rainfall amount 1583 mm out of which more than 90 % occurs under the impact of south western monsoon. It is drained by two major rivers, Subarnerekha and Murli. Both the rivers are perennial but most active during monsoon. Due to absence of proper water conservation structures surface runoff is very high and. Agriculture is mainly practiced based on the performance of monsoonal precipitation.

2. MATERIALS AND METHODS

In order to carry out the sub watersheds delineation process and morphometric data base generation Topographical sheets of Survey of India (SOI) and Digital Elevation model (DEM) of Landsat 2005 have been used (Tarboton, 2003). For delineation of sub watershed TNT mips software have been used while integration of different thematic layers for selection of suitable recharge structure was carried out in Arc GIS platform.

In the present study sub watersheds were delineated as per guideline set by National Remote Sensing Agency (NRSA) 1991. More than 30 first order streams were identified for the area as per Topographical sheets. Based on the stream numbers sub watersheds were delineated in by considering, flow accumulation, stream segmentation and bifurcation ratio. By applying filtering of dissolve polygon numerous small watershed polygons were merged with respective watersheds manually. Finally 37 sub watersheds were constructed for the entire Nayagram block.

From the GIS outputs various relief, drainage, linear and shape aspects of sub watersheds have been calculated (Nag & Chakraborty, 2003). All these aspects were studied under the quantitative morphometry which throw lights on the lithology and structural control of the basin. **Morphometr**y is the measurement and mathematical analysis of the configuration of the earth 's surface, shape and dimensions of its landforms (Clarke, 1966). With the help of such measurements vulnerability of watershed can be indirectly assessed in terms of soil erosion risk and water depletion. For delineating the vulnerability of each watershed, the study have used three shape parameters and four drainage parameters as shown in table below.

For sub watershed prioritization numeric rating was done for each sub watersheds as per selected morphometric parameters. In the process of prioritization all the sub watersheds were rated on the basis of obtained maximum and minimum value in each morphometric parameters. The study have used rating 1 for highest value in four **drainage parameters**, bifurcation ratio, drainage density, stream frequency and drainage texture, the next highest value of this parameters have given 2 and so on. The opposite value assignation was done in three **shape parameters**, form factor, circularity ratio and elongation ratio with lowest value has been assign with value 1 and offering 3 to highest values. Individual sub watershed score have been generated on the basis of average value of seven morphometric parameters. With the estimated average score of individual sub watershed prioritization was done by keeping least value with highest priority by putting priority 1, next highest to priority 2 and thus continues for 37 sub watersheds (Kanth & Hassan, 2012). In the process the sub watersheds categorized under high priority were selected for watershed management.

Table 1: Algebraic expressions of various morphometric parameters

Parameters	Formula	Reference	Highest	Lowest
Circularity ratio	$4\pi A / P^2$	Miller 1953	0.38	0.13
Form factor	A / L^2	Horton 1932	0.46	0.002
Elongation ratio	$(2/L) * \sqrt{A} / \pi$	Schumn 1956	3.2	0.17
Bifurcation ratio	N / N+1	Schumn 1956	3.2	1
Drainage density	L / A	Horton 1932	1.64	0.57
Stream frequency	N / A	Horton 1932	1.23	0.20
Drainage texture	N / P	Horton 1945	1.41	0.05

Where N represents for total number of streams of all order, A stands for Area of the basin in Km ^{2}, P is the perimeter of basin and L represents basin length in Km.

In order to management of highly prioritized sub water sheds both structure and location of water conservation structure selection is important. The location of water conservation structures are incorporated with the study conducted by IMSD (1995), (Chowdhury et al., 2009). For suggesting suitable water conservation site various physical parameters should be dealt with. In this study various GIS based thematic layers like; Land use land cover (LULC), Slope, Soil types and Stream order maps have been consulted. Mainly check dams and contour bounding structures are suggested for prioritized watersheds after the field verification. For suggesting the check dam sites 3rd order stream have been preferred (Pandey et al., 2011) in the agricultural land with gentle slope and fine textured soil. Contour bounding was suggested as per nature of present spring line found in the area.

3. RESULT AND DISCUSSION

Delineation of sub watersheds is helpful for development of various watershed management programs like soil and water conservation, resource generation and economic empowerments of distress households living within the watersheds. As per study 37 sub watersheds were identified in the Nayagram block out of 11 belongs to Murli Watershed (code no. 1, 6, 7, 9, 12, 22, 23, 30, 33, 36 & 37) and 26 belongs to Subarnarekha watershed (Figure 2). In the Murli watershed, largest sub watershed is found as Murli nadi (code no. 1) having area of 173.57 Km^2 and then the second largest is Dhobasol (code no. 6) with an area of 22.03 Km^2 whereas smallest is Krishnachandrapur (code no. 37) with an area of 1.04 Km^2 only. Kadam diha, Sita khal, Salbani and Rangiyam khal (code no. 2, 3, 4 & 5) are the largest sub watersheds among Subarnarekha watersheds ranging an average area of 47.38 to 35.33 Km^2.

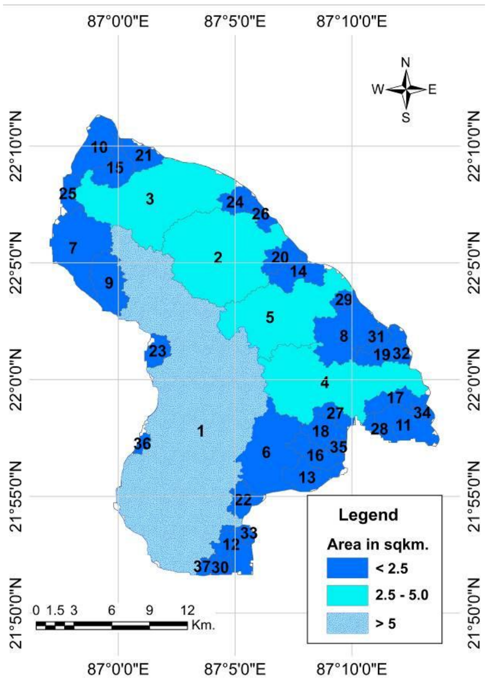

Figure 2: Sub watersheds of the study area

Most of the morphometric parameters are influencing the vulnerability dimension of sub watersheds. For the convenience of the analysis parameters are analyzed as per group stated below.

Shape parameters

Circularity ratio (Rc): For the calculation of circularity ratio, area of the watershed and circular circumference of the same watershed has been used. If the value gets higher vulnerability of the watershed reduced. More circular shape watershed represents less potential to surface run off and soil erosion. The minimum and maximum value of circularity is ranging from 0.38 to 0.13. All the sub watersheds were found lower than the idle circular basin. With decreasing circularity ratio retention capacity of surface water decreases which are showing high amount of vulnerability in all the watersheds. For an idle circular basin the value of circularity ratio should be less than 0.7854 (Chopra et al. 2005). Circularity ratio is found lowest in Rangiyam, Kamalatala & Chamarbandh sub watershed (0.13).

Form factor (Rf): As per Horton (1932) form factor has been calculated by the ratio between watershed area and square of the basin length. Smaller the value of form factor denotes low peak flow for longer duration. Usually the higher values are associated with flood and erosion. In such case disposal of water gets faster which increases the erosion activity. The maximum form factor is associated with Kadamdiha sub watershed (code no. 2) with value 0.46.

Elongation ratio (Re): By using the circular diameter and maximum length of the watershed elongation ratio is calculated. As the elongation ratio decreases run off gets maximizes. It is found between maximum of 3.2 to minimum of 0.17. The mean elongation ratio of Murli watershed is found lesser 0.82 compare to Subarnarekha watershed value of 0.87.

Table 2: Morphometric outcome of shape parameters for largest five sub watersheds

Murli sub watersheds						Subarnarekha sub watersheds				
SW no.	Watershed area	Circularity ratio	Form factor	Elongation ratio		SW no.	Watershed area	Circularity ratio	Form factor	Elongation ratio
1	173.57	0.22	0.23	0.89		2	47.38	0.19	0.46	1.02
6	22.03	0.28	0.08	0.28		3	45.75	0.24	0.26	0.45
7	18.47	0.20	0.07	0.96		4	43.57	0.25	0.06	0.32
9	9.96	0.23	0.01	0.53		5	35.33	0.13	0.04	3.2
12	6.74	0.19	0.09	1.10		8	16.20	0.14	0.02	2.12
A_M	22.27	0.23	0.05	0.82		A_S	10.83	0.23	0.08	0.87

A_M & A_S represents average value of Murli and Subarnarekha watershed

Drainage parameters

Bifurcation ratio(Rb): In every watershed relief and dissection is closely relates often which is represented by bifurcation ratio. It is a simple ratio between counts of stream of a given order to the counts of stream of next highest order (Horton 1945). High bifurcation ratio value suggests structurally distorted watersheds followed by high surface run off and low infiltration. Overall 15 out of 37 sub watersheds have been found with more than average value. Kamlatala sub watershed under Subarnarekha has found with highest bifurcation ratio of 3.2 which is more than double of mean bifurcation ratio of the area. Kashiya sub watershed is found with highest bifurcation ratio (2.46) under Murli watershed. Sub watersheds of Subarnarekha have got more bifurcation ratio (1.55) than Murli nadi (1.45) suggesting higher erosion risk towards the eastern side of the Nayagram block.

Drainage density (Dd): Length and spacing of stream is closely associated with the physical characteristics of watersheds like, lithology, permeability, rock formation and cultural characteristics like human interference through agricultural expansion and deforestation. Generally sub watersheds with higher drainage density values indicate lesser infiltration and maximum surface run off. For calculating the drainage density length of both perennial and non-perennial stream has been calculated as per unit area. Average drainage density of the block has been calculated as 1.09 Km per Km2. Among the major sub watershed highest drainage density was observed in Shalgeria under Murli nadi watershed having value 1.63 Km per Km^2. There is not much difference lies as per drainage density between Subarnarekha watershed (1.10 Km / Km^2) and Murli watershed (1.06 Km / Km^2).

Stream frequency (Fs): The stream frequency is the ratio between the total number of stream segments of all orders in a watershed area (Horton 1945). High stream frequency related to high degree of dissection and surface run off. The value of stream frequency in the different sub watersheds ranges from 1.22 to 0.198. It varied largely with a high standard deviation value of 0.30, due to diversified geologic condition. Highest stream frequency is observed in Dhobasol (1.22) under Murli watershed and Rangiyam (1.16) under Subarnarekha watershed respectively. Murli watershed has 27.80 % higher mean stream frequency in comparison with Subarnarekha watershed.

Drainage texture (Dt): For calculation of drainage texture a ratio is calculated between total numbers of stream segments of all order in a watershed to the perimeter of the concerned watershed (Horton 1945). As per drainage texture classification of Smith (1950) all the sub watersheds in the study area were found under very coarse (< 2) category. As per surface run off is concern it increases with the lesser texture ratio. Mean value of drainage texture is almost same in Subarnerekha watershed (0.33) and Murli watershed (0.32). Among the major sub watersheds under Subarnerekha watershed Rangiyam (code no. 5) has very fine texture having value 0.05 only.

Table 3: Morphometric outcome of drainage parameters for largest five sub watersheds

Murli sub watersheds						Subarnarekha sub watersheds				
ID no.	Bifurcation ratio	Drainage density	Stream frequency	Drainage texture		ID no.	Bifurcation ratio	Drainage density	Stream frequency	Drainage texture
1	1.78	1.10	1.05	0.11		2	2.53	1.14	1.07	0.26
6	1.67	1.25	1.22	0.16		3	2.04	1.10	0.89	0.34
7	2.46	1.05	1.02	0.24		4	1.64	1.26	1.07	0.22
9	1.2	0.98	1.10	0.20		5	1.64	1.21	1.16	0.05
12	1.33	1.09	1.03	0.10		8	3.2	1.13	0.80	0.11
A_M	1.45	1.06	0.92	0.32		A_S	1.55	1.10	0.72	0.33

A_M & A_S represents average value of Murli and Subarnarekha watershed

Prioritization

On the basis of qualitative analysis of drainage system watershed prioritization has been implemented for the area (Strahlar, 1964). This has been done following the simple concept, more the vulnerable higher should be the priority. With the help of average priority score final prioritization have been delineated. Sub watershed with number 27, 17, 14, 23, 2, 4, and 6 covering an area of 75.11 Km^2 have been found under the category high priority.

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Table 4: Priority score of different sub watersheds

Sw	Rc	Rf	Re	Rb	Dd	Fs	Dt	Av	Pr		Sw	Rc	Rf	Re	Rb	Dd	Fs	Dt	Av	Pr
1	13	33	25	11	19	8	29	19.7	24		20	35	7	3	19	18	10	19	15.9	5
2	11	37	27	2	14	6	16	16.1	8		21	27	31	11	7	35	26	13	21.4	30
3	22	34	16	4	20	16	12	17.7	16		22	29	23	9	20	25	3	7	16.6	10
4	28	26	10	15	7	5	21	16.0	6		23	37	13	1	8	30	19	2	15.7	4
5	1	25	37	14	12	2	37	18.3	17		24	16	35	22	9	10	17	14	17.6	14
6	31	28	7	13	8	1	24	16.0	7		25	25	18	13	26	36	36	27	25.9	35
7	12	27	26	3	24	11	18	17.3	11		26	6	30	32	27	21	35	36	26.7	36
8	4	21	34	1	15	21	28	17.7	15		27	23	11	15	10	13	12	9	13.3	1
9	18	17	20	24	27	4	22	18.9	19		28	15	6	23	28	28	34	3	19.6	23
10	14	36	24	12	16	14	23	19.9	26		29	32	4	6	29	33	33	5	20.3	27
11	19	15	19	21	17	18	20	18.4	18		30	3	24	35	30	32	32	33	27.0	37
12	10	29	28	22	22	9	31	21.6	31		31	9	3	29	31	4	31	30	19.6	22
13	24	20	14	16	9	23	15	17.3	12		32	21	2	17	32	34	30	26	23.1	34
14	8	12	30	23	3	7	25	15.4	3		33	5	22	33	33	1	28	32	22.0	33
15	2	32	36	17	11	22	34	22.0	32		34	30	1	8	34	31	25	6	19.3	21
16	26	19	12	5	5	29	17	16.1	9		35	34	5	4	35	29	24	1	18.9	20
17	17	10	21	18	2	15	11	13.4	2		36	33	14	5	36	6	20	8	17.4	13
18	7	16	31	6	23	27	35	20.7	29		37	20	9	18	37	37	13	10	20.6	28
19	36	8	2	25	26	37	4	19.7	25											

Sw represents Sub watersheds, Av stands for average priority score and Pr for priority rank

Water conservation site selection

The increasing population of the area has prompted intense utilization of land and water resources in the region. To keep pace with the demand land and water resource management is essential. Replenishing of ground water is not only helpful in the expansion of irrigation but also reduce the severity of acute drinking water shortages. With help of present study site of the water conservation structure has been proposed. For the proposed site selection four factors were consulted, Land use and Land cover (LULC), soil characteristics, regional slope and stream order.

Land use and Land cover (LULC):

By the supervised image classification LULC map of the area has been prepared (Lilesand and Kiefer 2000). As per LULC classification (Figure 3) the study area have been classified into nine land use classes. Out of total area 32.04 % area is presently comes under cultivable fallow and 21.83 % belongs to Lateritic surface. Only 1.59 % and 2.27 % area is covered by clear and sallow water respectively. Among all the LULC classes cultivable fallow was given maximum preferences during the identification water conservation site selection

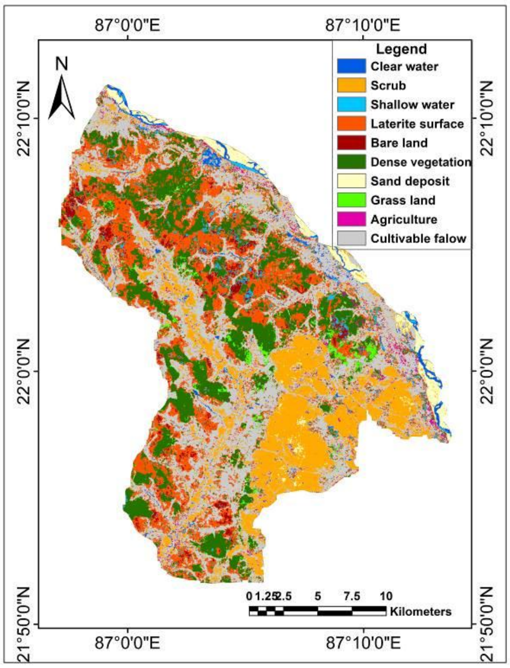

Figure 3: Land use and Land cover map of the study area

Soil characteristics:

Site selection of water conservation structures is greatly influenced by physical properties of soil. Soil properties like, texture, porosity, permeability etc. direct controls infiltration and water retention (Donahue et al., 1983). Soil with coarse grain has greater infiltration but it has limited capacity of water retention. On the basis of soil characteristics the study area can be divided into 4 soil categories namely, coarse loamy typic ustifluvents (W-64), coarse loamy typic haplsfalfs (W-67), fine loamy ultic paleustalfs (W-68), fine loamy aeric ochraqualfs (W-69) as shown in (Figure 4). Finer loamy soil has been preferred for the selection of conservation structure.

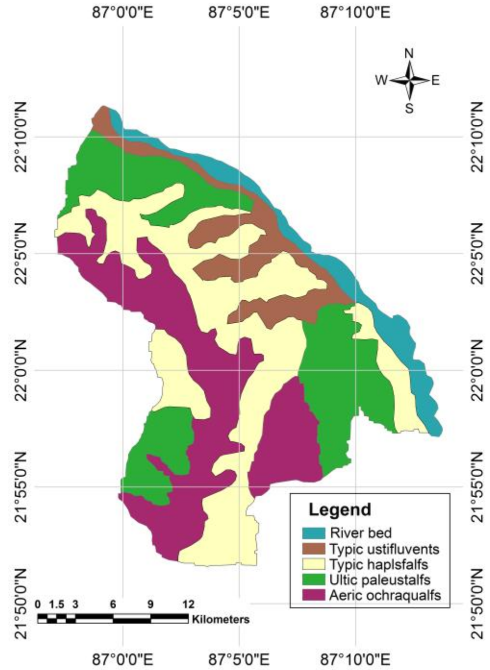

Figure 4: Soil map of the study area

Regional slope:

By adopting Wentworth method of slope calculation, a slope map of the study area was prepared (NRSA 1995). On the basis of slope value, entire study area has been divided into five classes as shown in Figure 5. Most of the study area falls under the category of very gentle slope (239.40 Km2) ranging between 2^{O} to 4^{O}. For suggesting water conservation structures flat to very gentle slope has been preferred.

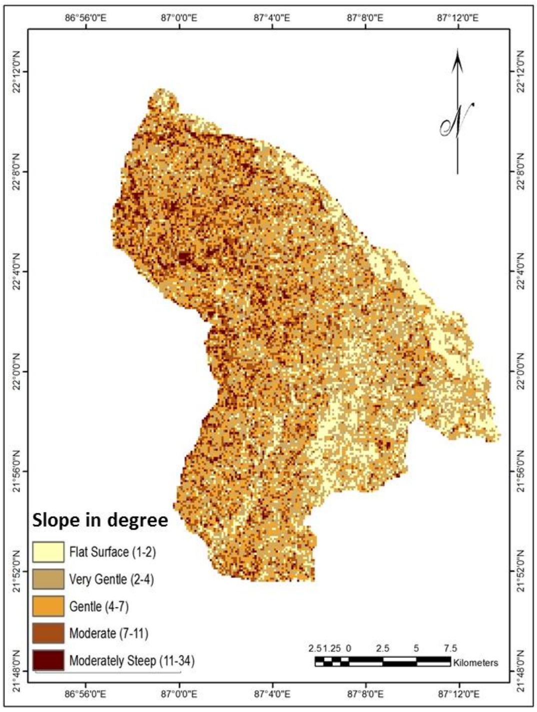

Figure 5: Slope map of the study area

Stream order

The drainage pattern of the area is found dendritic in nature. Total number of 521 streams is found in the various sub watersheds (Figure 6). Total number of first, second, third and fourth order stream as per Horton (1932) is found as 41.27 %, 28.41%, 13.63 % and 16.70 % respectively. Lengths of all streams are calculated as 598.42 Km. with individual length of first, second, third and fourth order stream as 249.86 km, 186.48 km, 81.92km and 80.16 km.

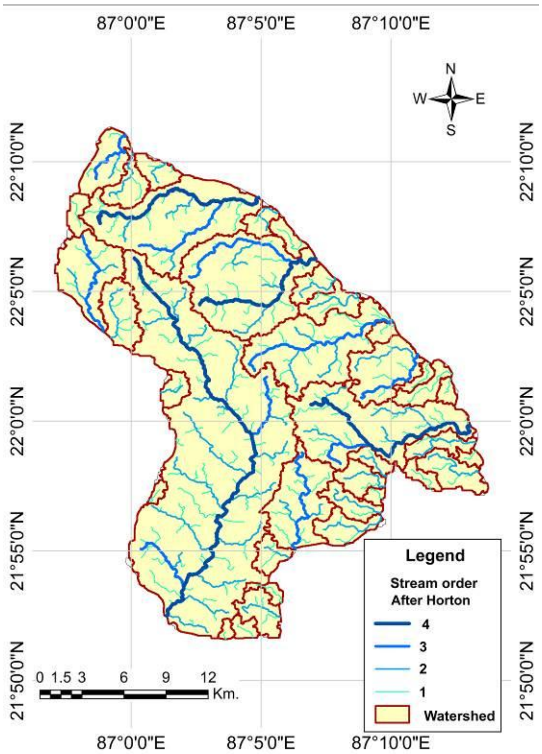

Figure 6: Different order of the streams

Conservation structures

Depending on the physical condition of the study area check dam structure has been proposed for the 7 prioritized sub watersheds (Figure 7). For the construction of dam a minimum of 55 meter elevation has been set depending on the hydrological condition of the area. Site of the dam is proposed on the 3 rd or 4 th order river of the sub watersheds along with pre requisite conditions set as per land use, soil and slope criteria. Proposed check dams will help to reduce the soil erosion of 75.11 Km ^{2} area and improve the water table to put 67.20 Km ^{2} (13.41 %) additional area of the bock under irrigation through improved water level. A contour bounding project will be also helpful to be constructed at an altitude of 75 m for incorporating integrated watershed management program.

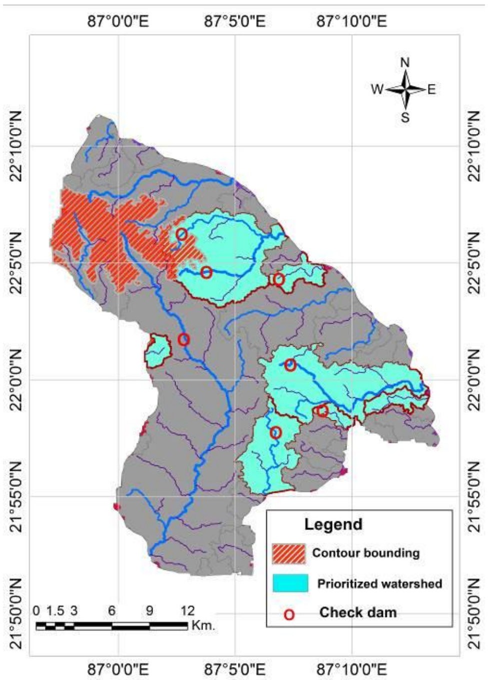

Figure 7: Water conservation sites with proposed structures

4. CONCLUSION

For management of land and water resources knowledge of morphometric parameters is very much essential. Sub watersheds having highest amount of vulnerability in terms of Structural modification have been prioritized. Out of 37 Sub watersheds of the study area 7 watersheds covering an area of 75.11 Km ^{2} have been selected as prioritized. To maintain balance between regional development and economic constraint management of prioritized sub watersheds are promoted through this study. Along with morphometric parameters various physical aspects like land use, soil, slope and drainage characteristics are also used for predicting water conservation site. The study have suggested total 7 check dams for prioritized sub watersheds which will help to increase the land and water utilization efficient.

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