Prioritization of micro-watershed based on morphometric analysis and runoff studies in upper Darna basin, Maharashtra, India

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ORIGINAL ARTICLE

Prioritization of micro-watershed based on morphometric analysis and runoff studies in upper Darna basin, Maharashtra, India

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Abstract

The watershed prioritization based on morphometric analysis and surface runoff has more importance in soil and water conservation and further planning at micro-level. The present study demonstrates the usefulness of GIS for prioritization of the micro-watersheds of the upper Darna River basin of Nashik District of Maharashtra. The aim of the paper is to apply a composite score of morphometric analysis and surface runoff for prioritization of sub-watersheds for identification of soil erosion and high runoff. The study area extends between 19° 36′ N to 19° 48′ N latitudes and 73° 39′ E to 73° 44′ E longitudes which comprise the area of the upper Darna River basin, and it covers around 389.6 km^2 area. Arc GIS Software Ver.10.2 and Global Mapper software have been used for morphometric analysis. Rational formula has been employed to find out rainfall intensity, time of concentration and surface runoff. Entire study area is divided into 140 micro-watersheds, named DARN_A for first-, DARN_B for second-, DARN_C for third-, DARN_D for forth- and DARN_E for fifth-order streams. The finding shows that among 140 micro-watersheds, 19 micro-watersheds consist of 278.17 km^2 area of the total study area, which represents 78.75% areas that are depicted in high soil erosion and excessive runoff. Therefore, these 19 micro-watersheds required immediate attention to provide soil conservation measures.

Keywords Morphometric parameters · Watershed prioritization · Surface runoff · Micro-watershed

Introduction

Morphometric analysis of drainage is crucial for proper planning of watershed as it gives information about the basin characteristics in terms of slope, topography, soil conditions, runoff characteristics and surface water potential. Through prioritization, morphometric analysis and prediction, estimation of surface runoff of the watershed could be helpful for identification of critical micro-basins for applying conservative measures. The rainfall-runoff transformation process at the watershed scale is an extremely complex phenomenon. However, the hydrological behavior of a watershed and its runoff producing capacity can be related to its morphological characteristics (Kumar et al. 2012; Aher et al. 2014).

In western Maharashtra, most of the watersheds show high potential of soil loss and surface runoff. The upper Darna River basin is located in western Maharashtra and therefore selected as a study area for identification of high soil erosion and runoff for conservation planning. Assessment of the watershed has been useful for resource management, planning and implementation of development of soil and water conservation erosion control in river catchment.

Several studies have been conducted on watershed prioritization based on morphometric (i.e., linear, areal and shape) parameters determined using remote sensing and GIS techniques such as Nag (1998) used RS techniques for morphometric analysis and groundwater studies in the Chaka sub-basin, Purulia District, West Bengal. Biswas et al. (1999) used RS and GIS techniques for prioritization of nine watersheds of Nayagram block, Midnapore District,

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West Bengal, in terms of morphometric parameters. Khan et al. (2001) were assessed 68 sub-watersheds for prioritization of the Guhiya basin, western Rajasthan, India, on the basis of their erosivity and sediment yield index values. Vittala et al. (2004) utilized RS and GIS in morphometric parameters examination of sub-watersheds of Pawagada zone, Tumkur region, Karnataka. Nookaratnam et al. (2005) estimated sediment yield index and morphometric parameters utilizing remote sensing and GIS for locating check dam by prioritization of small-scale watersheds. Mesa (2006) determined drainage characteristics of Lules River basin, Tucuman, Argentina, by morphometric parameters. Thakkar and Dhiman (2007) used remote sensing and GIS techniques for morphometric analysis and prioritization of the eight mini-watersheds of Mohr watershed, located in Kheda District of Gujarat, India. Javed et al. (2009) had attempted prioritization of sub-watersheds based on morphometric and land use characteristics using RS and GIS techniques in Kenera watershed, Guna District, Madhya Pradesh. Mishra and Nagarajan (2010) have been working on morphometric analysis and prioritization using GIS and RS to study maximum soil erosion sub-watersheds of the Tel River of Odisha, India. Gupta and Singh (2010) used the geomorphologic parameters for the development of a reliable response model for prediction of runoff and sediment yield from small watersheds of Mahi catchment in Gujarat, India.

Avinash et al. (2011) used geomorphology and morphometric parameters prioritize the sub-basins of the Gurpur River basin, southern Karnataka, India, to identify the most deficient/surplus zone of groundwater using RS and GIS techniques. Besalatpour et al. (2012) used the Soil and Water Assessment Tool (SWAT) to identify and prioritize the critical sub-basins in a highly mountainous Bazoft watershed, southwestern Iran. Gajbhiye et al. (2013) used RS and GIS techniques for morphometric analysis and prioritization of 14 sub-watersheds of Manot River catchment, India. Hajam et al. (2013) have carried out morphometric analysis using GIS techniques to assess geo-hydrologic characteristics of Vishav drainage basin and identified the ground water potential zones. Aher et al. (2014) proposed weighted sum analysis method for prioritization of sub-watersheds of Pimpalgaon Ujjaini watershed located in Maharashtra, India. The quantitative analysis of morphometric parameters was done using remote sensing and GIS techniques. Baidyanath Kumar (2015) has been working on

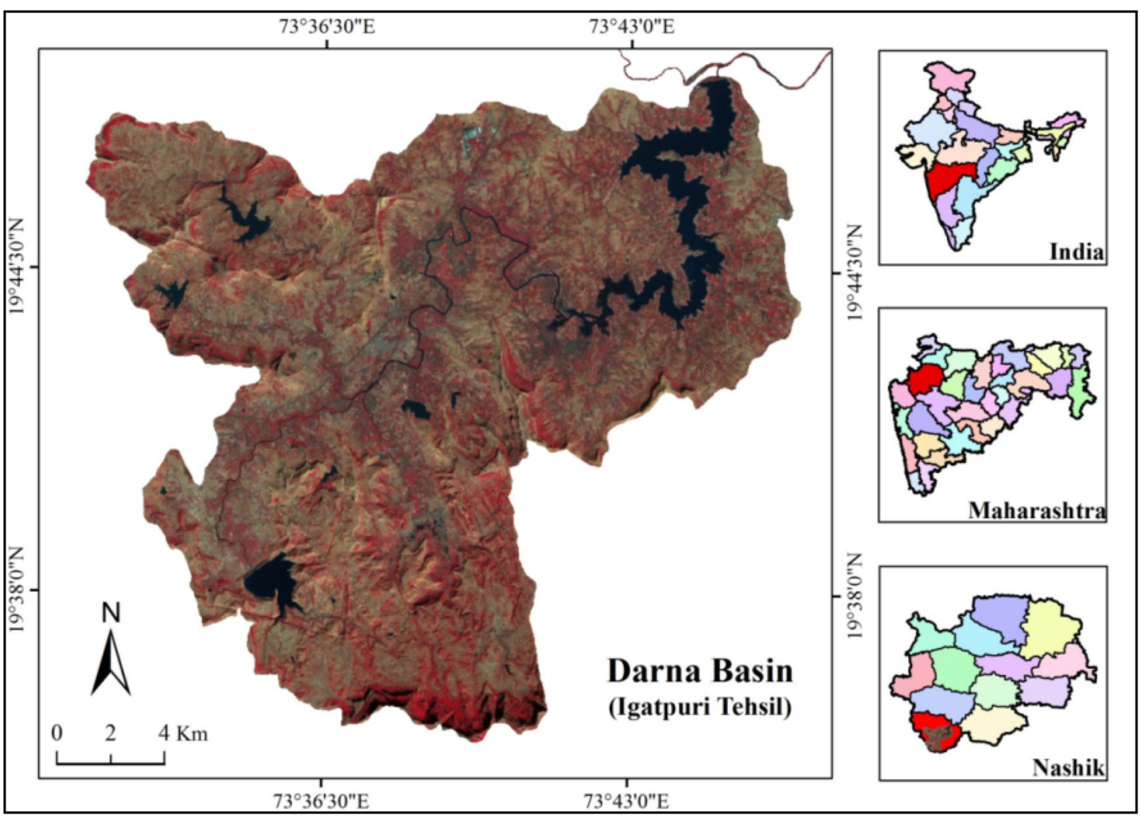

Fig. 1 Location map of upper Darna basin

prioritization of watersheds through surface runoff in the Pambar river basin. The runoff values, arrange in hierarchy for prioritization and use to find out high runoff basins for conservation. Kiran et al. (2016) applied the morphometric and runoff parameters using RS and GIS techniques for prioritization of Silai River basin, West Bengal. Gopinath, et al. (2016) performed watershed prioritization based on morphometric analysis coupled with multi-criteria decision-making approach for Kuttiyadi River basin, Kerala. Pathare (2018) applied prioritization on the basis of morphometric analysis and surface runoff estimation to identification of high soil erosion and excessive runoff sub-basins of Darna watershed, Maharashtra, India. Gaikwad and Bhagat (2017) assessed morphometric parameters and prioritized sub-watersheds of the Kas River basin, India, using RS and GIS techniques. Anurag Malik et al. (2019) proposed the weighted sum analysis method for hilly 14 sub-watersheds (SWs) of Naula watershed located in an upper Ramganga River basin, Uttarakhand State, India, for identification of highly susceptible sub-watersheds. Kudnar and Rajasekhar (2019) have studied morphometric analysis and cycle of erosion in Waingangā basin, India.

The present study highlights the usefulness of GIS for morphometric analysis and surface runoff for prioritization of the micro-watersheds of upper Darna River basin. The main objectives of this paper: (1) to perform the morphometric analysis and surface runoff of the upper Darna River catchment, (2) to apply composite score of morphometric analysis and surface runoff for prioritization of micro-watersheds and (3) to identify micro-watersheds of high soil erosion and runoff for conservation planning.

Study area

Darna River is one of the tributaries of Godavari River in the Nashik District of Maharashtra State. It originates on the northern slopes of Kulung Hill at elevation 1040 m in Sahyadri ranges about 13 km southeast of Igatpuri Tahsil. The upper Darna River basin extends between 19° 36′ N to 19° 48′ N latitudes and 73° 39′ E to 73° 44′ E longitudes (Fig. 1). The area covers around 389.6 km^2, and Dana Lake is one of the important lakes of the upper Darna River basin. The watershed has 1520 m maximum elevation, and the lowest elevation is 570 m with rugged topography. The upper catchment area receives high rainfall (3000–4000 mm), and annual temperature ranges between 18 and 38 °C. It has long and meandering course, and its bed is wide and sandy. On the right bank at Belu village, the river Darna confluences with river Kadva and on the left bank, it has tributaries namely Vaki, Unduhol, Valdevi and others such as Bham Nadi.

Table 1 Formulas for calculation of morphometric parameters

Morphometric parameters	Formulas	References
Stream order (u)	Hierarchical order	Strahler (1964)
Stream length (L_u)	Length of the stream	Horton (1945)
Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$ where L_u = stream length of order ‘u’ and N_u = total number of stream segments of order ‘u’	Horton (1945)
Stream length ratio (R_l)	$R_l = L_u/L_u - 1$ where L_u = total stream length of order ‘u’ and $L_u - 1$ = stream length of the next lower order	Horton (1945)
Bifurcation ratio (R_b)	$R_b = N_u/N_u + 1$ where N_u = total number of stream segments of order ‘u’ and $N_u + 1$ = number of segment of next higher order	Schumm (1956)
Basin relief (B_h)	Vertical distance between the lowest and highest points of watershed	Schumm (1956)
Relief ratio (R_h)	$R_h = B_h/L_b$, where B_h = basin relief and L_b = basin length	Schumm (1956)
Ruggedness number (R_n)	$R_n = B_h \times D_d$ where B_h = basin relief and D_d = drainage density	Schumm (1956)
Drainage density (D_d)	$D_d = L/A$ where L = total length of streams and A = area of watershed	Horton (1945)
Stream frequency (F_s)	$F_s = N/A$ where N = total number of streams and A = area of watershed	Horton (1945)
Texture ratio (R_t)	$R_t = N_1/P$ where N_1 = total number of first-order streams and P = perimeter of watershed	Horton (1945)
Form factor (F_f)	$F_f = A/(L_b)^2$ where A = Area of watershed, L_b = basin length	Horton (1945)
Circularity ratio (R_c)	$R_c = 4\pi A/P^2$ where A = area of watershed, $\pi = 3.14$ and P = perimeter of watershed	Miller (1953)
Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)}/L_b$ where A = area of watershed, $\pi = 3.14$ and L_b = basin length	Schumm (1956)
Length of overland flow (L_g)	$L_g = 1/2D_d$ where D_d = drainage density	Horton (1945)
Constant of channel maintenance (C_c)	$C_c = 1/D_d$ where D_d = drainage density	Horton (1945)

Materials and methods

The methodology of the present work is focused on the application of morphometric analysis and runoff studies of the upper Darna catchment. The survey of India (SOI) topographical map numbers 47 E/9, 47 E/10, 47 E/13 and 47 E/14 on the scale of 1:50,000 have been used for preparation of base map for stream network. The topographical maps are geo-referenced and rectified using Arc GIS Software Ver.10.2. The drainage network of the study area has been digitized using Global mapper software. Strahler's (1964) stream ordering method has been employed, and the total area of basin has been divided into 140 micro-watersheds based on stream order. The nine morphometric parameters of areal, linear and relief aspects such as drainage density (D_d), stream frequency (F_s), texture ratio (R_t), form factor (F_f), circularity ratio (R_c), elongation ratio (R_e), ruggedness number (R_n), constant of channel maintenance (C_c) and length of overland flow (L_g) calculated by using various formulas for individual basins are presented in Table 1. The rainfall data are obtained from hydrological department, MERI, Nashik, for the period 1976 to 2014. The rational formula has been employed to find out rainfall intensity, time of concentration and surface runoff volume for each of the 140 micro-watersheds (Eqs. 1, 2, 3). The data sources and methodology used in this study are shown in Fig. 2.

Morphometric analysis

The morphometric analysis is one of the significant tools to find out prioritization of micro-watershed. The formulae made by Horton (1945), Strahler (1964), Miller (1953) and Schumms (1956) have been adopted for the calculation of linear, areal and relief aspects for 140 delineated micro-watersheds of the upper Darna catchment. Prioritization rating of all the 140 micro-watersheds of upper Darna catchment is carried out by allotting ranks to the individual

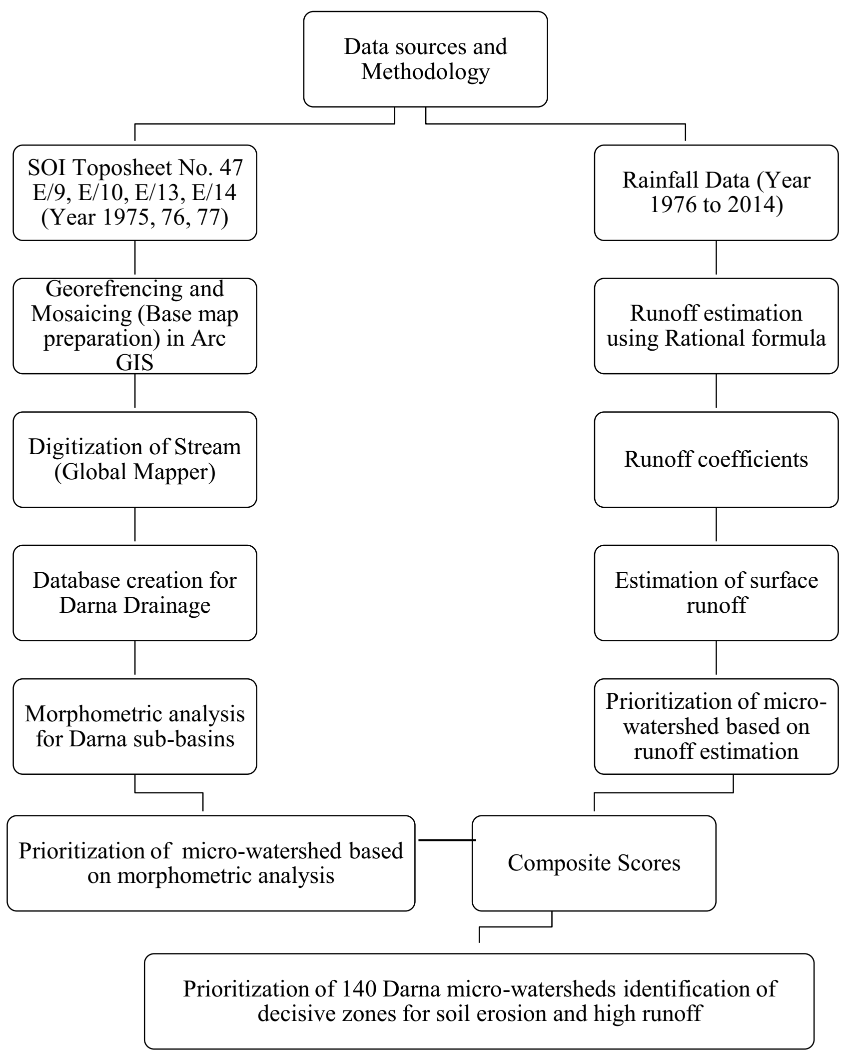

Fig. 2 Flowchart of data sources and methodology

parameter. The compound value of all parameters has been calculated. The highest compound parameter value of micro-watershed is assigned with lower priority and vice versa. Micro-watersheds have been broadly classified into five priority zones as per their compound value. Accordingly, an index of very high (< 25), high (26–50), medium (51–75), low (76–100) and very low (> 100) priority has been obtained by order (Fig. 3). The high priority indicates a need of retrieval processes and an action plan for protection and conservation of soil.

Runoff estimation

Rational formula has been employed to find out rainfall intensity, time of concentration and peak surface runoff volume for each of the 140 micro-watershed. Time of concentration of upper Darna catchment has been calculated by following equations (Government of Maharashtra 1996)

$$t = 0.01947(k)^{0.77} \quad (1)$$

t = Time of concentration in minutes

$$k = \sqrt{L^3 \div H} \quad (2)$$

where L = difference in elevation between most remote point and outlet in meters; H = maximum length of travel in meters; peak volume of runoff is

$$Q = \frac{CIA}{360} \quad (3)$$

where Q = the peak discharge or the quantity of runoff in (m^3/s); C = coefficient of runoff; I = rainfall intensity, in millimeters per hour; and A = area of the watershed, in Hectare.

On the basis of the calculated peak surface runoff of individual micro-watershed, priority ranking has been allotted. The micro-watersheds with the highest peak runoff value (low ranking) are assigned by higher priority and vice versa. Micro-watersheds have been broadly classified into five priority zones as per their computed peak surface runoff value. Accordingly, an index of very high (0–30), high (31–60), medium (61–90), low (91–120) and very low (121–150) priority has been obtained by order (Fig. 4). The high priority indicates high runoff and low infiltration; therefore, there is a need to step up and an action plan for protection and conservation of soil and water.

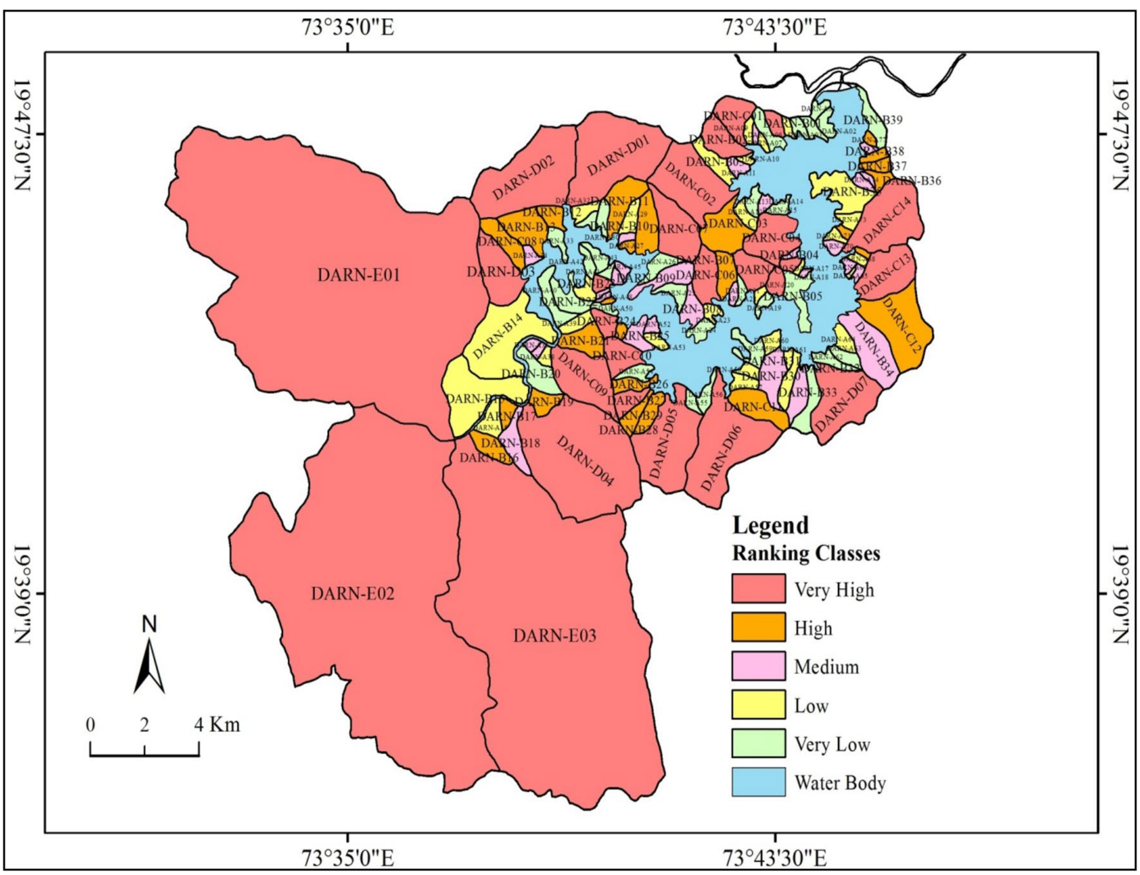

Fig. 3 Micro-watershed based on morphometric analysis

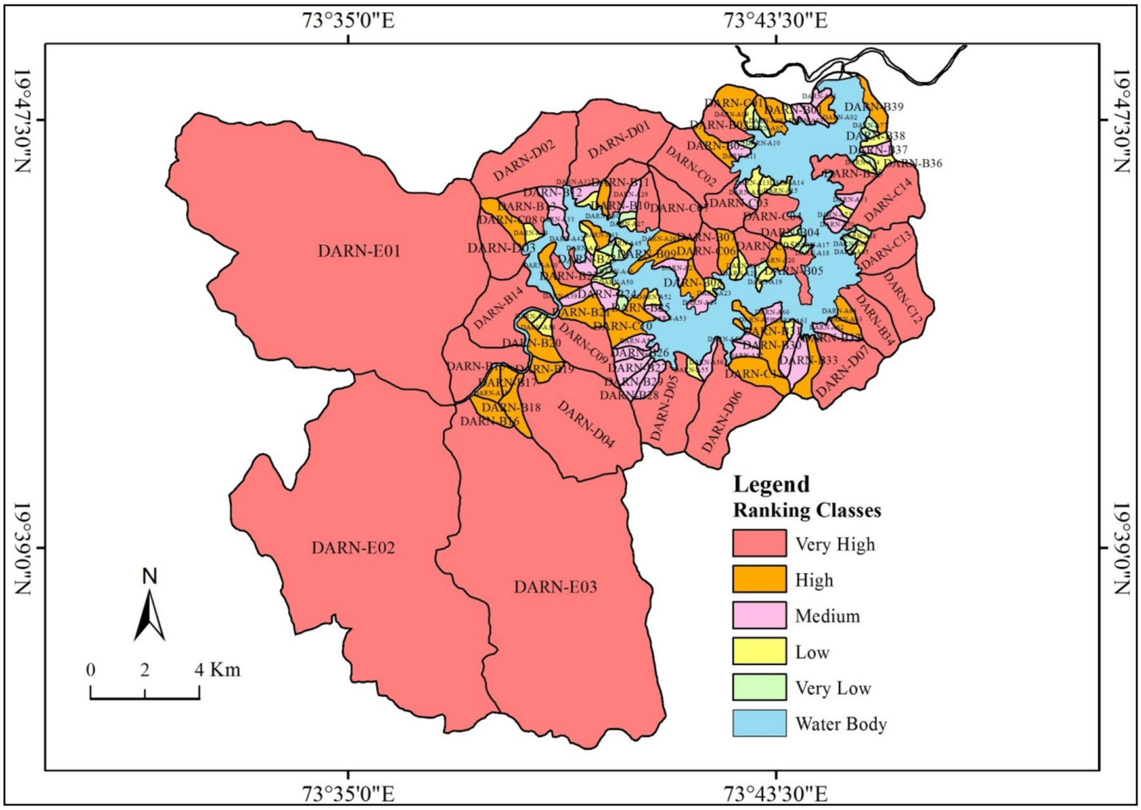

Fig. 4 Micro-watershed based on surface runoff

After the analysis, compound parameter of morphometric analysis and surface runoff values are calculated and prioritization rating for 140 micro-watersheds is carried out.

Result and discussion

The integrated study of morphometric analysis and surface runoff values shows very high soil erosion and high runoff. The calculated drainage density (5.8 km/km$^{2)}$ and stream frequency (17.6 per km^2) show high value of upper Darna catchment that indicates low permeability and high surface runoff. The texture ratio value (8.3) of the study area is high which indicates high runoff. The composite score of morphometric analysis and surface runoff of 140 micro-watersheds of upper Darna basin prioritized in five categories i.e. very high priority, high priority, mediumpriority, low priority and very low priority. The study reveals that 19 micro-watersheds were found very high priority, 19 micro-watersheds were found high priority, 27 micro-watersheds were found medium priority, 36 micro-watersheds were found low category, and 39 micro-watersheds were found very low priority (Fig. 5). The 19 micro-watersheds in very high priority (DARN_E01, DARN_E02, DARN_E03, DARN_D01, DARN_D02, DARN_D03, DARN_D04, DARN_D05, DARN_D06, DARN_D07, DARN_C02, DARN_C04, DARN_C05, DARN_C06, DARN_C07, DARN_C09, DARN_C13, DARN_C14 and DARN_B02) consist of 278.17 km^2 area of the total study area, which almost represent 78.75% of the area that is depicted in high soil erosion and excessive runoff (Fig. 5). Decisive zones have been thus identified for conservation, planning and management.

(*DARN* Darna sub-basin Code)

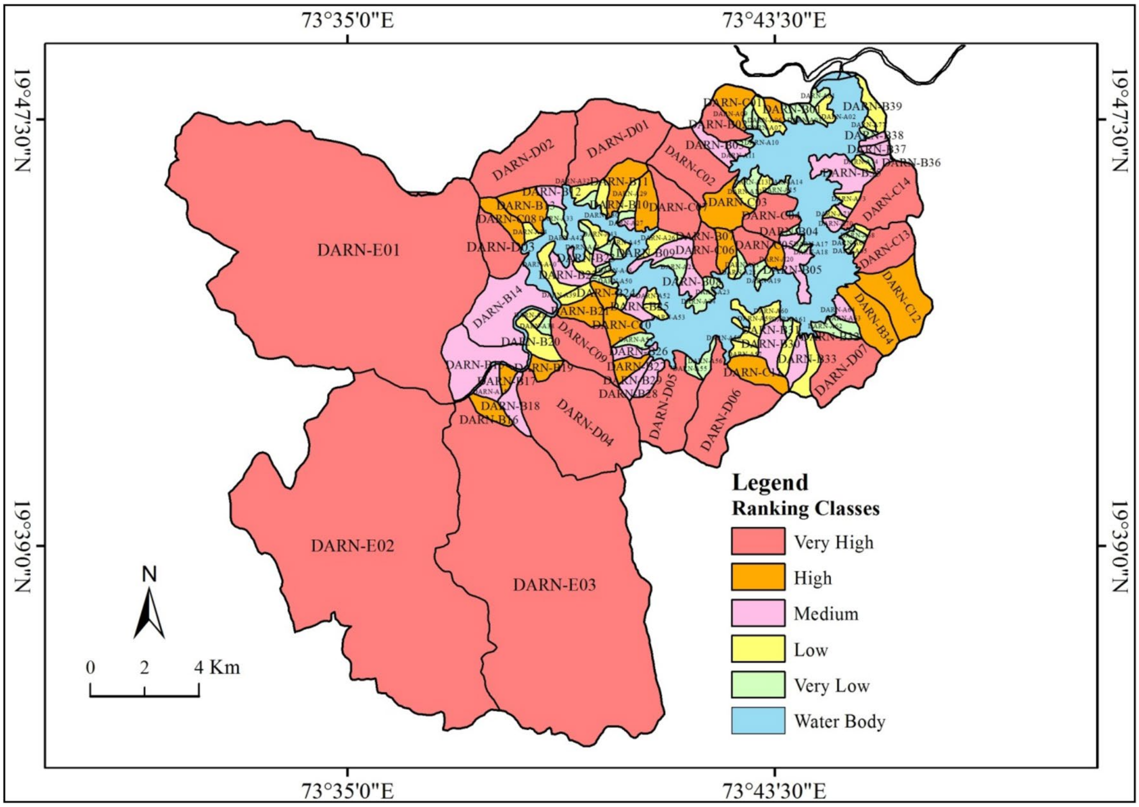

Fig. 5 Micro-watershed based on morphometric analysis and surface runoff

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