Micro-watershed Delineation and Potential Site Selection for Runoff Water Harvesting Using Remote Sensing and GIS in a Hilly Area of Bangladesh

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Abstract The dry-season water scarcity is a problem of crop intensification in many hilly areas of the world. The rainwater or runoff water harvesting (RWH) could be a potential solution for those areas. The methodologies and the criteria for selecting the site for RWH structure are available for macro-watershed but not for micro-watershed. This study aims at selecting a suitable location of RWH structure for micro-watershed through all possible combinations of methodologies and criteria. For this, we developed a conceptual framework where a participatory approach, field and questionnaire surveys with remote sensing and GIS techniques were adopted. After preliminary selection of the watershed site through field surveys, four micro-watersheds were delineated using ArcGIS hydrological tools. Watershed delineation was carried out using SRTM DEM (automatic-delineation) and Google Earth (manual-delineation). Integrated approaches involving both biophysical and socioeconomic factors were followed for identifying the potential site for the RWH structure. In regards to biophysical assessment, various thematic maps, such as stream networks, slope, soil and land use were developed to describe the characteristics of each micro-watershed. The socioeconomic considerations were the number of population to be benefited, possibilities of expanding farming, and accessibility to the watershed reservoir in each micro-watershed. Thus, the results obtained from biophysical and socioeconomic determinants reveal that the micro-watershed (MWS)-2 and MWS-3 are most suitable for the same scores and recommended for constructing the RWH structure. However, various attempts need to consider regarding the choice of crops on hill slopes, conservation of soil, and management of the structure for getting full potential benefits from the watershed reservoir.

Keywords: watershed delineation, characterization, runoff water, remote sensing, GIS

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1. Introduction

Chattogram Hill Tracts (CHT) occupied about 13,300km[2] covering about 8% of the total landmass of Bangladesh. It's 85% of hills are medium to steep slope [1,2]. During the rainy season (June-October), shifting cultivation is the predominant crop production system in the region [3,4,5]. The short-rotation shifting cultivation practiced by the farmers is now uneconomical and environmentally inappropriate. Therefore, modification of shifting cultivation was suggested for sustainable food production by utilizing the production potential of sloping lands [3,6,7]. During the dry winter period (December-February), crop production is mainly constrained by inadequate rainfall and drying up of creeks, rivers, and streams or *charas*, the excellent physical resources for supporting agricultural production through creating water reservoirs [8,9]. The CHT lies in a high rainfall (2419-3121 mm) area, where 80% of the total annual rainfall occurs between May and October [10]. However, farmers are hardly able to utilize that water in crop production and household uses due to lack of rainwater harvesting facilities, scarcity of natural water reservoirs, and less storage capacity of the existing water reservoirs. For areas suffering from water scarcity, rainwater harvesting (RWH) is a potential solution by supporting irrigation in the valley land by gravity-flow, and hill summit and hill slope by suction mode pumping [8,11]. So, the constraints of crop production in the hills

during the dry season can be removed by developing appropriate watersheds in suitable locations.

A total of 659 small and large watersheds were delineated by FAO in CHT through area-based delineation [12]. Some other organizations are also involved in identifying potential watersheds and the place of constructing dam or water storage structures for conserving rainwater for irrigation. For RWH site selection, a detailed understanding and analysis of several interrelated biophysical factors such as soil type, land use, slope, soil drainage, rainfall are essential [13,14,15,16]. Besides, socioeconomic criteria with the integration of biophysical factors were found effective [17,18]. All these are lacking in selecting and developing watersheds in the region. Nowadays, GIS and remote sensing techniques are most capable for the assessment, monitoring, and management of resources covering large and inaccessible areas and to select a suitable site for RWH harvesting structure [19,20,21]. These techniques can help to perform the watershed analysis comparatively in a shorter time and cost-effective way [22,23]. However, the integrating efforts of using these techniques along with field surveys in watershed delineation and characterization were not tried hitherto in CHT.

Khagrachari district, a part of the CHTs, is the extensive hilly and forested area in Bangladesh. The cropping intensity of the region is 139% that is far below the national average [24]. Conversely, the average yearly rainfall is more than 3000 mm, which is much higher compared to the other areas of Bangladesh. The low cropping intensity is due to the uneven distribution of rainfall throughout the year and an acute shortage of water in the dry season. Importantly, irrigation sources, including small water bodies, rivers, canals, and streams are incapable of supplying water for dry season crop production. However, there is an ample opportunity of harvesting rainwater by constructing small watershed structure/dam in the downstream of the hill land to irrigate the *rabi* (winter) crops. Such a water supply system inevitably facilitates to increase cropping intensity in the valley by allowing a triple cropping system and permanent horticultural crop cultivation at hill summit and hill slope [8]. The created reservoir could also be used for fish production and harbor many other aquacultures. In the area, the socioeconomic development program must be a micro-watershed (100 to 1000 ha) basis as the shape of the watershed is seemly to manage water, soil, and production resources for the success of agricultural development activities. Therefore, the study was conducted for selecting a suitable site of runoff water harvesting (RWH) structure considering biophysical and socioeconomic factors through field surveys, and geospatial-based delineation, and characterization of micro-watershed.

1.1. Watershed Location

The watershed area is situated at Khagrabill within Ramgarh Bazar mouza under Ramgarh union at the western side of Ramgarh upazila and part of Fatikchari upazila of Chittagong District (Figure 1). It lies between 22°54'10.8" and 22°56'52.8" N Latitudes and between 91°42'43.2" and 91°45'57.6" E Longitudes. This extent of the watershed is only 1584 hectare and within a perimeter of 21.7 km. The watershed is characterized mostly by low hills of Dupi-Tila formation having nearly level to slopping hill summits; slightly slopping to very steep slopes at the middle and lower part of hills; slightly level to level piedmont areas, valleys at the base of the hills; and nearly level to level broad valleys along the streams and in between the hills. Moderately coarse to coarse textured soils developed on closely dissected low hills of Dupi-Tila formation. Hill of this area is mostly north to south aligned.
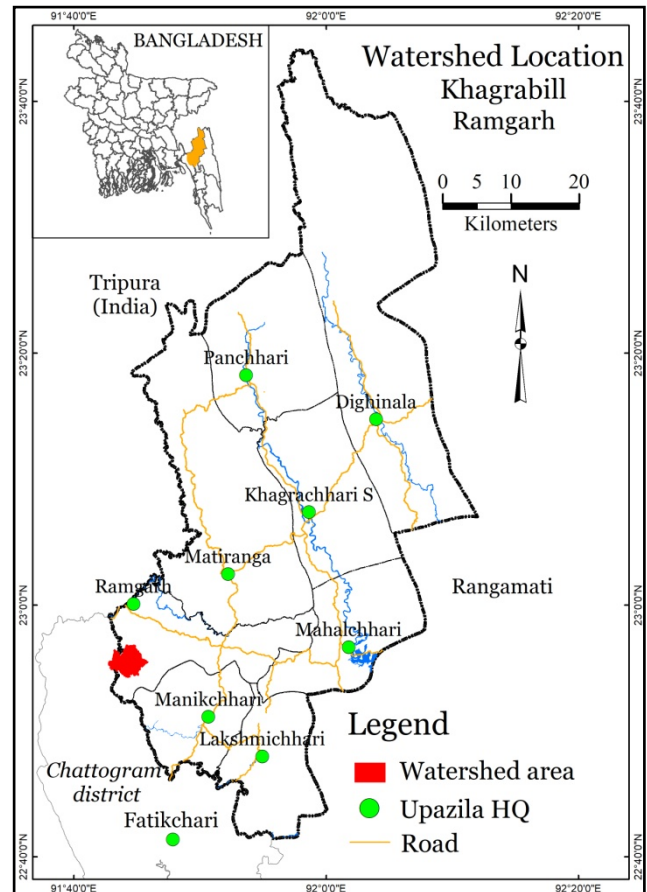

Figure 1. Location of the study area

2. Methodology

2.1. General Working Conceptual Framework

The detailed methodologies adopted for selecting micro-watersheds and identifying a suitable location for constructing runoff water harvesting (RWH) structure is illustrated in a flowchart (Figure 2). A preliminary selection of the watershed area was based on consultation meeting and focus group discussion (FGD) with the related stakeholders, and a questionnaire survey with the farmers. The micro-watersheds were delineated based on selected pour points (outlets), followed by characterizing the watersheds. Finally, a potential site of RWH was recommended for developing a micro-watershed.
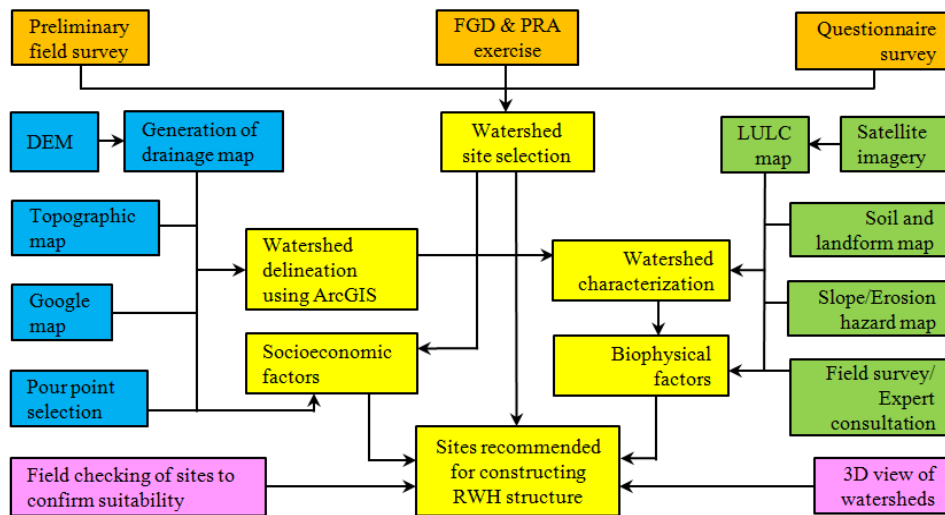
Figure 2. General working conceptual frameworks for selecting micro-watershed and identifying suitable location for runoff water harvesting (RWH) structure

2.2. Field Survey

A participatory approach was adopted to collect necessary information through the use of various participatory rural appraisal (PRA) methods and tools. Several field surveys were conducted to observe the farmers' field level situation and perform ground-truthing. A questionnaire survey included the interviews of the farmers to get insights into the real scenarios of the farm practices and associated problems, development possibilities, and livelihood systems of the watershed area. A focus group discussion (FGD) was held with the Local Leaders, Union Council Representatives, Leading Farmers, and Personnel from the Department of Agricultural Extension (DAE). A transect walk with FGD participants was held to observe the feasibility of runoff water harvesting (RWH) structure and to locate its suitable site of interest. Ground-level surveys were also conducted to confirming the remotely sensed data acquired through DEM and satellite images. The extracted stream elevation data through Google Earth Pro were checked through GPS device (GARMIN 64s). The success of watershed development heavily depends on site selection and construction design of the hydraulic structure [25]. For this, the issues considered were (i) accessibility, (ii) farmers' participation, (iii) area to be brought under irrigation facilities, (iv) suitability of constructing RWH structures based on climate, hydrology, topography, agronomy, soils and socio-economics [18], (v) possibility of enhancing agricultural production and (vi) total population to be benefited.

2.3. Watershed Delineation

Watershed delineation was carried out using SRTM (Shuttle Radar Topography Mission) Digital Elevation Model (DEM)-based delineation (automatic delineation) followed by manual (hand) delineation. In DEM-based delineation, the boundary was created automatically by computer. The manually delineated boundary was based on Google image and ground verification. Watershed boundaries were drawn out from 30 m resolution DEM using hydrological tools in ArcGIS [26,27,28]. DEM filling function was performed to avoid irregular

stream/drainage networks. For showing the direction of water flows out of each cell of a filled elevation raster, the flow direction tool was used. The flow accumulation tool was used that tabulates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. Stream networks were derived from a flow accumulation raster and represented as shapefile. As the ultimate goal is to select a suitable site for watershed structures, some point-based micro-watersheds were created instead of area-wide watersheds. Therefore, the pour point tool was used to ensure the selection of points of high accumulated flow during delineating watersheds. These watershed boundaries were compared with the manually delineated boundaries. It was essential as the watershed area is small and low-resolution DEM-based boundary gave the irregular shape of the watersheds. The main streams of each micro-watershed were characterized in respect of length, elevation differences, and slope gradients.

2.4. Watershed Characterization

A detailed soil survey was conducted in the four micro-watershed areas adopting standard soil survey procedures [29]. The sentinel image-2 of 11 February 2017 with 10 m spatial resolution was used to identify landforms and other surface features. It helped to identify and delineate three major landform units: dissected low hills, flat to gently sloping narrow valley, and almost flat broad valley. A rapid traversing was conducted to check the unit boundaries. A detailed soil survey was carried out in the watersheds to identify soil series with their extent based on a semi-detailed soil survey previously carried out by the Soil Resource Development Institute (SRDI) in the area. The investigation was also done on land types, drainage and slope gradient to establish their relationship with soil series. For this, various field tools like GPS, Soil Survey Kits, and different Soil Survey Equipment were used. Land use and land cover (LULC) map of 10 m spatial resolution was generated based on sentinel image-2. After the completion of image preprocessing, sub-setting the image to the extent of the watershed area was done. Afterward, the unsupervised clustering technique was

performed in classifying the image objects that initially produced 24 classes in 12 iterations. Based on the similarity, the classes were regrouped into four and rectified with correct ground points. Based on the classified image, a LULC map of the micro-watersheds was generated that contained four types of land use viz. cropland-1, cropland-2, hill forest and bare land.

2.5. Suitability Assessment of RWH Structure

The suitability assessment of the micro-watersheds for constructing runoff water harvesting (RWH) structure was done considering biophysical and socioeconomic factors suggested by FAO [30]. The biophysical factors were slope or topography, soil and landform, land use and land cover, stream length and slope gradient and climate. For this, various GIS map layers were prepared and fixed the criteria of rating for suitability assessment through expert consultation and gave the scores. The socioeconomic factors were the number of population to be benefited from the watershed reservoir, extensive farming possibilities, and accessibility to the watershed reservoir. These factors are rated through PRA exercise and key persons' interviews. Based on the overall ratings, we recommended the micro-watershed and the suitable place of constructing the RWH structure.

3. Result and Discussion

3.1. Field Survey and FGD

The farming problems and the challenges faced by the farmers in the Khagrabill watershed area have been ranked through PRA exercise and resource mapping. Based on the observation and data, three major farming problems and challenges in the watershed area were identified. These are the scarcity of irrigation water on sloping land with an inadequate water management system, low production associated with *Jhum* cultivation system, and insufficient extension activities leading to unfamiliar with the mechanized cultivation practices. A shortage of modern agricultural machinery has also been noticed. Besides, problems with the production inputs like improved seeds, fertilizers, insecticides, lack of credit facilities, and the low market price of their products due to poor communication and marketing facilities existed. Middlemen's influence is one of the causes of low market prices. The nonexistence of the agro-processing industry and damaging or reducing the quality of the agricultural products is not uncommon. A preliminary discussion was held with the different Stakeholders like Local Leaders, Union Council Representatives, Leading Farmers, and Personnel from the Department of Agricultural Extension (DAE) to conduct the study smoothly. The Leading Farmers organized a Focus Group Discussion (FGD), where the roles of different participants and stakeholders were discussed. A farm walk was done by the FGD participants along the stream (drainage channel) to observe the feasibility of constructing a rainwater harvesting structure and located some possible sites. Different participants had different opinions on the site selection from the perspective of their interests. Finally,

they selected the pour points (locations of RWH structure) and opined to bring probable micro-watersheds (MWS)-2 and MWS-3 together for development.

3.2. Delineation of Micro-watersheds

3.2.1. Boundary Delineation

As the digital elevation model (DEM) enables to terrain analysis in 3D space, so it is efficient to delineate watershed using the Arc Hydro tool in ArcGIS [26]. The DEM represents the continuous elevation values over a topographic surface and the elevation difference with its direction of the Khagrabill watershed area (Figure 3a). In general, the southeast has the highest elevation value (87 m), whereas the northwest has the lowest elevation value (7 m). The elevation also represents the slope range that progressively decreased from a similar direction. Although there are some other directions of declining slopes, much of slope declines in the southeast to northwest direction. It indicates that most of the streams and water flow directions tend to a similar path. The elevation in the filled dam (Figure 3b) is more visible that ensures the connectivity of streams. Disconnected stream networks are a thoughtful problem in assessing stream length, stream order, and stream density [31]. After processing, the DEM with depressions filled, flow direction and flow accumulation data sets optionally produced drainage networks that visualize the possible micro-watersheds. The majority of the streams started from the uphill slope that continuously extended the lower elevation position in the northwest (Figure 3c-d). Some pour points were selected on raster streams for delineating watershed, and the points donating the water flow to those streams are termed as a sub-watershed as per [32]. As the pour point is the location where runoff water harvesting structure could be built [33], the adjustment of pour point position was done that slightly shifted from the actual ground position. Micro-watersheds were validated satisfactorily by comparing them with the 3D Google Earth map. Thus, the area of each micro-watershed was calculated that ranged from 246 to 557 ha (Figure 3f).

3.2.2. Accuracy of Boundary

Accurate area delineation is imperative for watershed management and its success. The automated watershed delineation using GIS hydrological tools is useful in the hilly areas with limited accessibility. It also allows for easy display of watershed boundary in maps with relevant data and assessment of a variety of watershed characteristics like streams, soils, land use, etc. The manually-delineated (Google Earth-based) and the DEM-based delineated boundaries of four mini-watersheds are compared visually in Figure 4. There is a small difference between the manually-delineated and the DEM-based delineated and indicated 0.13% less estimation in DEM-based delineation for four micro-watersheds. Except for MWS-1, others are less estimated ranged from 0.50 to 3.05%, while 7.27% is overestimated in MWS-1 (Table 1). It was reported that the SRTM-based watershed area was 0.66% larger than the watershed delineated manually [34]. The manually-delineated boundaries are comparatively smooth over the DEM-based boundary. In reality, 30-m

resolution DEM is not enough to obtain a smooth watershed boundary for a small area. Therefore, the DEM-based followed by manual could be of better use in area delineation of a small watershed. Even the SRTM DEM performed consistently better than the other types of DEMs in the case of all three automatic watershed delineation tools and produced only a 2.99% average error [35].
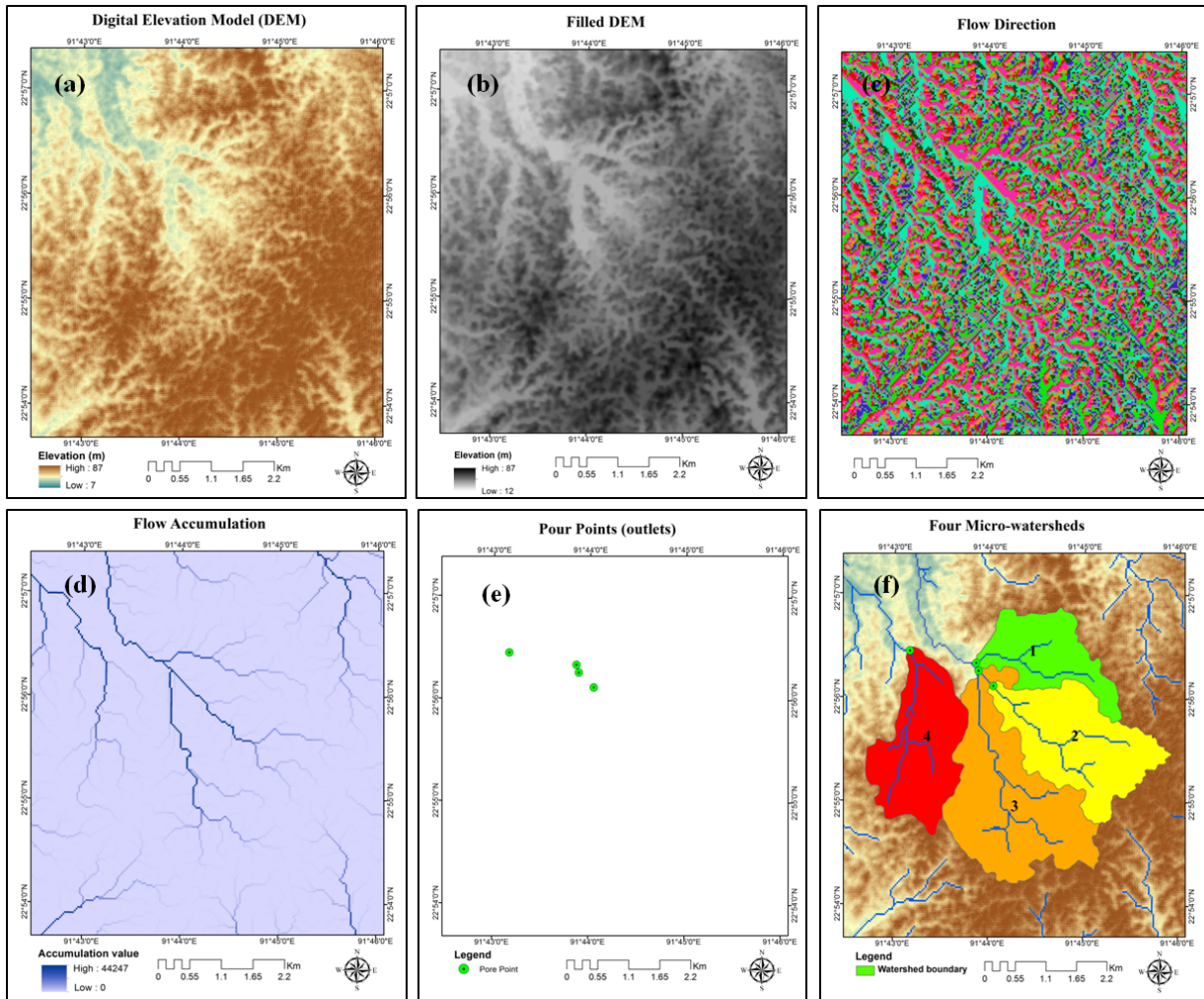
Figure 3. Results of watershed delineation including (a) Digital Elevation Model (DEM), (b) Filled DEM, (c) Flow direction, (d) Flow accumulation (stream networks), (e) Pour points (outlets) and (f) Delineated micro-watersheds
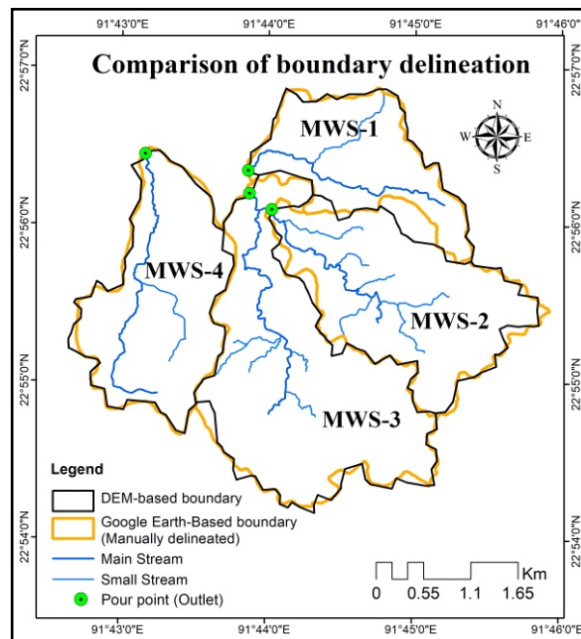
Figure 4. Comparison between DEM-based and manually (Google Earth-based) delineated watershed boundaries

Table 1. Change in area of watershed boundaries

Micro-watersheds	Area (ha)		%change
	Manual	DEM-based	
MWS-1	246	264	7.24
MWS-2	420	407	-3.05
MWS-3	557	554	-0.50
MWS-4	361	357	-1.17
Total	1584	1582	-0.13

3.3. Watershed Characterization

3.3.1. Stream Characteristics

The extracted stream networks from DEM of 30 m resolution were indicative and did not fit well with terrain conditions. Some errors are common in the generation of stream networks from DEM. So it is advocated two or more than two delineation procedures to get better output [35]. Therefore, stream networks were also drawn from Google image following the stream networks generated by DEM for accuracy. Figure 5 (upper) illustrates the differences in stream networks between SRTM DEM-based and Google Earth-based delineation. However, some distortion observed between these two methods of stream delineation. The elevation profile of the stream networks is an advantage of Google Earth-based stream networks delineation. Figure 5 (lower) shows the elevation profiles of four major streams of the micro-watersheds. All the streams show the drop of elevation over their respective lengths towards the bottom of the catchment. The length of the streams ranged from 2.85 (stream-A) to 3.52 Km (stream-D) with a mean of 37.5 (stream-C) to 40.8 m (stream-A) elevation. The elevation differences are comparatively less in stream B followed by stream C (Table 2). However, elevation loss and gain were high in both the streams compared to the other two streams. The average slope gradients for the ascending and descending stream segments were 2.2% and −2.4% for stream B and 2.5 and -2.6% for stream C, respectively. The differences in average ascending and descending slope gradient for streams B and C are comparatively smaller than that of streams A and D. This indicated better water flow in streams B and C. Both of the streams B and C have at almost equal elevation level at their lower catchments and joins together.

3.3.2. Slope Characteristics and Soil Erosion

The slope map of the micro-watersheds estimated that the area covered in 15-30% slope class is as high as 40.8% (Figure 6a, Table 3). The flat and relatively flat area slope with less than 5% covers 2.7% of the area. The gently sloping area covered by a 5-15% slope is 21.0%. The very steep (>50%) area covers only 6.5% of the total area. It also shows that the area under the different slope of four micro-watersheds distributed almost equally except for MWS-1, where hills constituted by comparatively steeper slopes. Both MWS-2 and MWS-3 occupied more than 7% of land under nearly level to gently sloping (up to 15%) that could be more suitable for RWH structures compared to others. The cultivable land having a slope of up to 8% was indicated suitability for the RWH structure [21]. From Figure 6a, MWS-2 and MWS-3 are having a vast area of land together with the almost flat landscape. The elevation profile of streams and slope with less-steep and flatter areas of these two watersheds near the pour point has the advantage of causing slow movement of water that remained on the soil surface.

Soil erosion and land use depend on hill slopes. In general, the higher the hill slope, the more severe is the soil erosion. The rate of soil erosion varies with the vegetation coverage along the hill slope. Based on the hill slope, erosion hazards in the watershed area are classified into four viz. very slight, slight to moderate, moderate to high, and high to very high (Figure 6b). The farmers there practiced shifting cultivation on sloping land without considering biophysical aspects. Therefore, the removal of the forest for shifting cultivation adversely affects the environment causing severe soil erosion [36]. A high to very high soil erosion hazard occurs in the land having more than 30% slopes. Some valley areas having almost flat land are experiencing very slight erosion hazards due to occasional flash floods. However, the practicing hedgerows on steep slopes and the adoption of agroforestry production techniques can reduce soil erosion by up to 80% in the area [37].
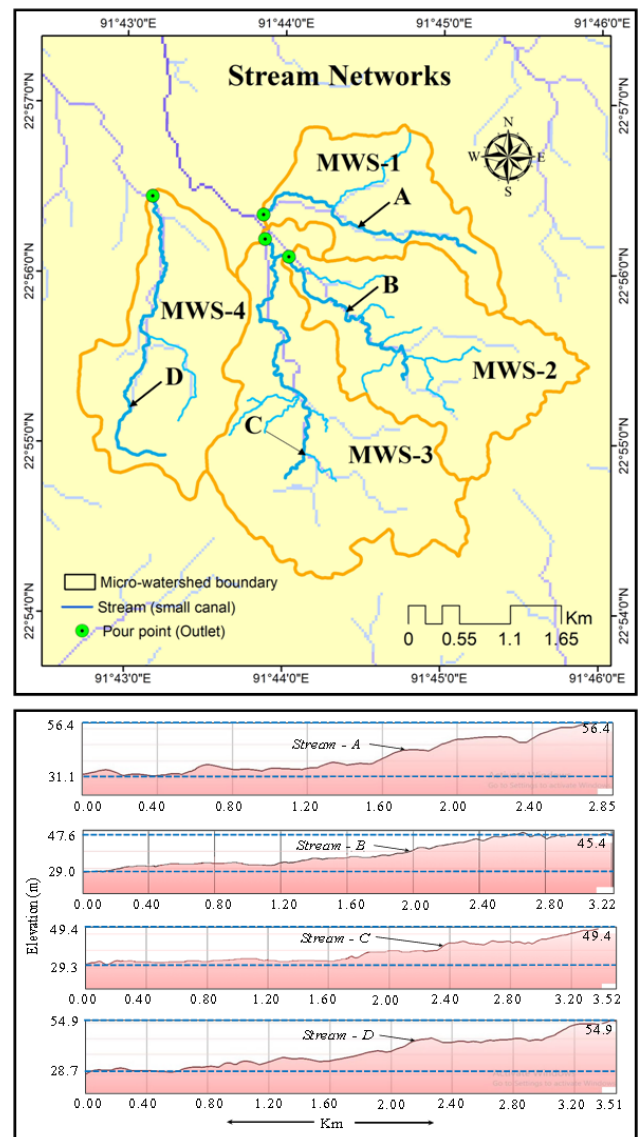
Figure 5. Stream networks map (upper) and long profile and elevation differences of the major streams (lower) along the watershed

Table 2. Length, elevation and slope of major streams of four micro-watersheds

Stream	Stream length (km)	Elevation (m)		Elevation difference (m)	Elevation gain/loss (m)	Average gradient (%)
		Range	Mean			
A	2.85	31.1-56.4	40.8	25.3	39.0/-14.2	2.0, -1.4
B	3.22	29.0-47.6	38.1	18.6	44.8/-31.4	2.2, -2.4
C	3.52	29.3-49.4	37.5	20.1	55.8/-37.8	2.5, -2.6
D	3.51	28.7-54.9	39.3	26.2	40.8/-15.9	1.8, -1.1
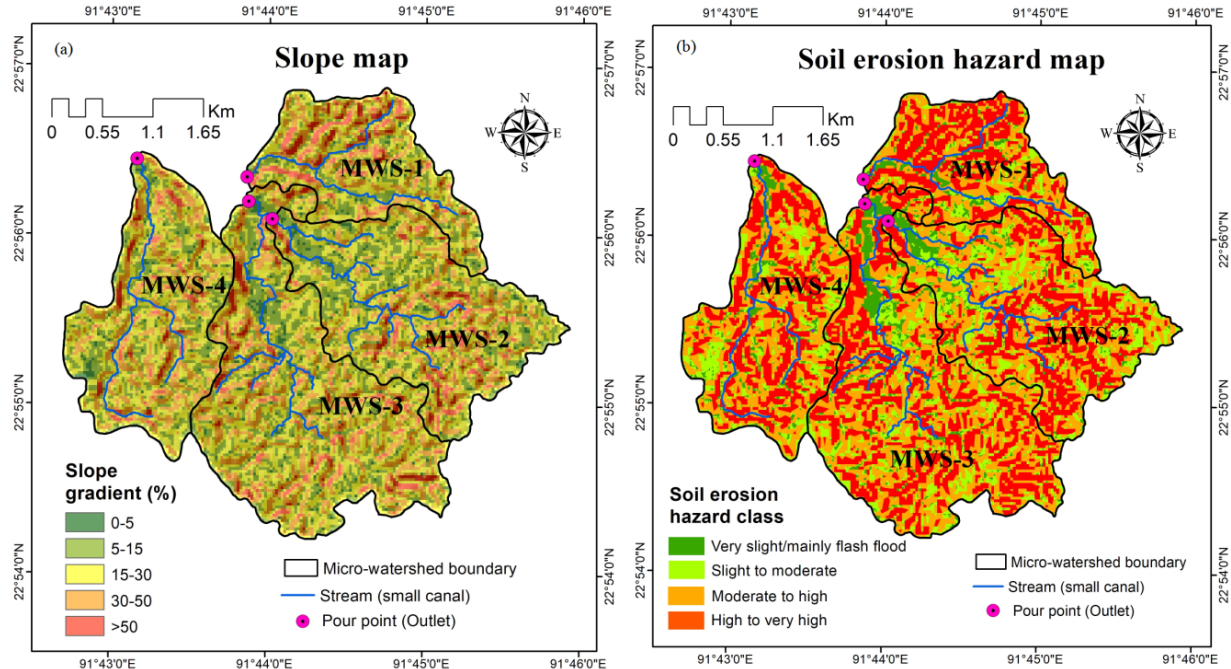
Figure 6. Maps showing (a) slope (b) soil erosion hazards of four micro-watersheds

Table 3. Distribution and extent of slope classes in Khagrabill watershed area

Slope class	Area (ha)				Total Area (ha)	Soil erosion hazards [38]	Crop suitability
	MWS-1	MWS-2	MWS-3	MWS-4			
Nearly leveled (<5%)	5 (0.3)	12 (0.8)	15 (1.0)	10 (0.6)	42 (2.7)	Very slight	Very good
Gently sloping (5-15%)	41 (2.6)	102 (6.5)	113 (7.1)	75 (4.7)	332 (21.0)	Slight to moderate	Good
Moderately sloping (15-30%)	96 (6.1)	170 (10.7)	227 (14.3)	153 (9.7)	646 (40.8)	Moderate to high	Fair
Steep (30-50%)	77 (4.8)	109 (6.9)	168 (10.6)	107 (6.7)	461 (29.1)	High to very high	Less suitable
Very steep (>50%)	27 (1.7)	26 (1.6)	34 (2.1)	16 (1.0)	103 (6.5)	High to very high	Restricted for agricultural uses
Total	246	420	557	361	1584		

3.3.3. Soil and Landform Characteristics

The landform and topography of the micro-watersheds are characterized mostly by dissected low hills of Dupi-Tila formation, slightly level to level piedmont valleys at the foothills, and nearly level to level broad valleys along the streams. The soils are coarse to moderately fine textured and developed on closely dissected low hills. Based on the physiography, soils, and development possibilities within the watershed, three mapping units are recognized (Figure 7a, Table 4). Mapping unit-1 is well-drained dissected low hills and comprised of an area of 1142 ha. Three soil series, namely Khadimnagar, Lama, and Rangamati of the textural classes of sandy loam, clay loam, and clay loam to clay, respectively, were identified. In general, soil fertility of these soils was found low to very low. Mapping unit-2 is predominantly narrow valley land and comprised of an area of 112 ha (7.1%). These are high land to medium high land dominated by Mirsarai>Mogachari>Karnaphuli

soil series. The Mirsarai soil series are characterized by dark brown mottled, grey-colored clay loam soil. This soil is hard and highly acidic in reaction. The Mogachari soil series is brown mottled, grey-colored clay soil having high acidic, and Karnaphuli series is brown to deep brown mottled, grey-colored sandy loam soil. This soil is friable, and soil reaction is neutral to slightly acidic. All the soil series are mostly well-drained to imperfectly drained. In general, soil fertility of these soils is relatively good. Mapping unit 3 is a relatively broad valley covering an area of 329 ha (20.8%) and level to nearly level land. These are high land to medium high land dominated by Mirsarai>Mogachari>Karnaphuli soil series. These soils are mostly imperfectly to poorly drained. In general, soil fertility of these soils is also good. Valley lands dominated in MWS-3 (9.9%) out of four watersheds. The MWS-2 and MWS-4 also contained 6-7% of valley land. In valley land, the Mirsarai soil series is predominant and suitable for the production of a wide range of crops.

Table 4. Land form, soil and hydrological properties of four micro-watersheds

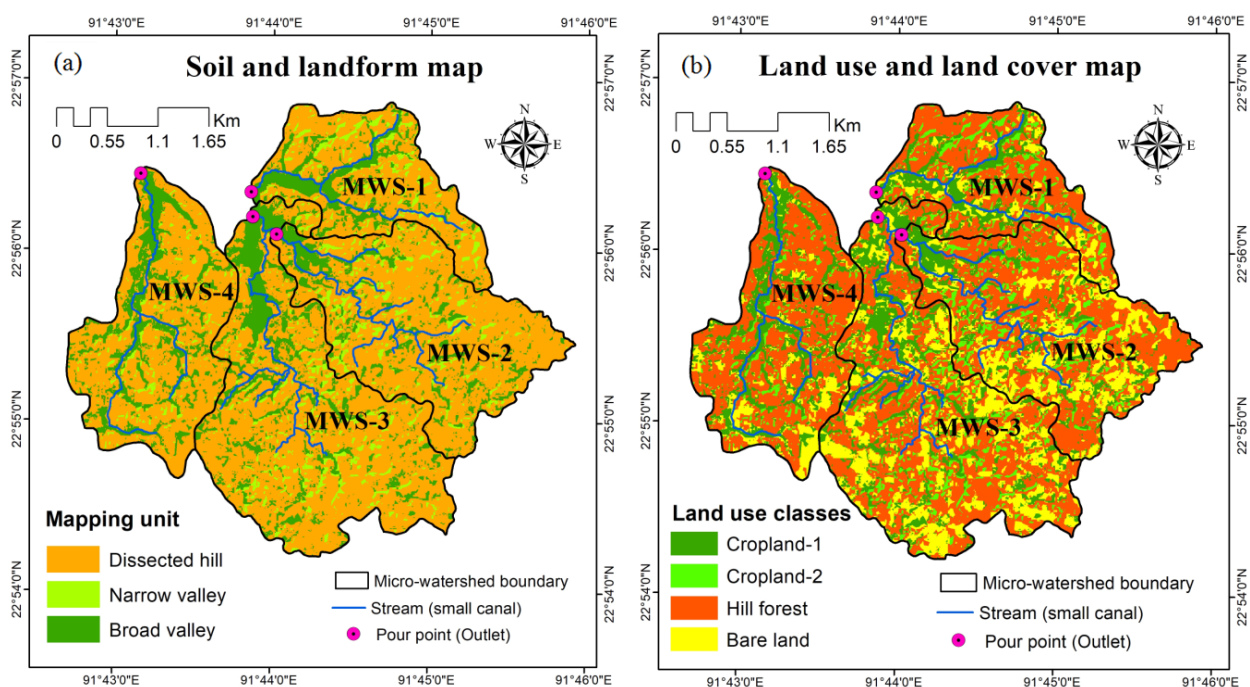| Mapping unit	Land form and topography	Soil association	Area (ha)				Total Area (ha)	Soil drainage
			MWS-1	MWS-2	MWS-3	MWS-4		
1	Low hill; Dissected	Khadimnagar-Lama Rangamati-Lama	166 (10.5)	324 (20.4)	401 (25.3)	252 (15.9)	1142 (72.1)	Well drained
2	Narrow Valley; Flat to gently undulating	Mirsarai-Karnaphuli Mogachari-Mirsarai	26 (1.7)	31 (1.9)	39 (2.5)	16 (1.0)	112 (7.1)	Well to imperfectly drained
3	Broad Valley; Almost flat	Mirsarai-Karnaphuli Mogachari-Mirsarai	54 (3.4)	65 (4.1)	117 (7.4)	93 (5.8)	329 (20.8)	Imperfectly to poorly drained
Total			246	420	557	361	1584	

3.3.4. Land Use and Land Cover

The valley soils are the best natural resource in the area so far their presence, productivity, capability and suitability for continued cultivation of dry and wetland crops. The cropland-1 land-use class is the broad valley where farmers practiced double-cropping systems. *T aman* rice is there cultivated during the monsoon and *boro* rice during the dry period if irrigation water becomes available (Figure 7b, Table 5). The cropland-2 is mostly the narrow valleys located in the upper catchment where *T aman* rice is the dominant crop during the monsoon period. In both areas, *kharif* vegetables are most common, but *rabi* vegetables are rare, only possible by utilizing residual soil moisture. In the hills, the majority of the land occupied by relatively sparse forest (833 ha), of which some are recently established fruit gardens. Some dense forest exists, but it could not be brought under the individual mapping unit. Un-classed State Forest (USF) and horticultural plantations are the most common land use on those hills along with seasonal crops, bamboos, shrubs, thickets, and grasses. The areas are not very far from the traditional village where Bengali inhabitants who are naturally not accustomed to the *Jhum* (shifting cultivation) system are residing. The bare hill areas occupied 324 ha. The utilization of this hill land is possible for developing orchard as an emerging crop production system if dry season irrigation facilities prevail. Land use is a significant parameter for selecting a rainwater harvesting site [39]. Thus, the MWS-4 containing 9.3% of valley land is the most suitable land for intensive cultivation through augmenting irrigation facilities. The MWH-2 and MWS-4 also have some valley land and considered suitability for the RWH structure.

Table 5. Land use and land cover (LULC) of four micro-watersheds

Land use class	Area (ha)				Total Area (ha)	Land use/cropping pattern
	MWS-1	MWS-2	MWS-3	MWS-4		
Cropland-1	50 (3.2)	65 (4.1)	109 (6.9)	89 (5.6)	313 (19.8)	Boro-Fallow-T aman (rice); Fallow-Fallow-T aman (rice); Vegetables
Cropland-2	27 (1.7)	31 (1.9)	39 (2.5)	17 (1.1)	113 (7.1)	Fallow-Fallow-T aman (rice); Boro-Fallow-T aman (rice); Vegetables
Forest land (sparse)	136 (8.6)	221 (14.0)	264 (16.7)	212 (13.4)	833 (52.6)	Social forest, Horticultural plantation, Seasonal crops, Jhum and USF, Thickets and grass
Bare land	33 (2.1)	103 (6.5)	145 (9.2)	43 (2.7)	324 (20.5)	Fallow/Jhum
Total	246	420	557	361	1584	

Figure 7. Maps showing (a) soil and landform and (b) land use and land cover of four micro-watersheds

Table 6. Suitability assessment of the micro-watersheds for RWH structure as per criteria cited in literature

Criteria	Scores*				References for selecting the criteria
	MWS-1	MWS-2	MWS-3	MWS-4	
Bio-physical					
1. Topography: slope (<15%)	1	4	4	3	[18,23,42]
2. Soil: texture (fine textured soil/sandy clay loam)	2	3	4	3	[43]
3. Land use and land cover (Barren, shrub and scrub land)	2	3	4	4	[18,44,45]
4. Hydrology: Stream flow order (2-4)	2	4	4	3	[44,46,47]
5. Climate: Rainfall (>150-750 mm/year)**	4	4	4	4	[18]
Score (Biophysical)	11	18	20	17	
Socio-economic***					
1. Community (number of village/ population): >2	1	4	3	2	[48]
2. Farming system: (extent of irrigated/dry area, livestock etc.)	1	4	3	1	[48]
3. Accessibility (distance to settlement, roads, streams)	3	4	4	2	[18,49]
Score (Socioeconomic)	5	12	10	5	
Overall score	16	30	30	22	

*Scores: 4-very suitable, 3. Suitable, 2-moderately suitable, 1- marginally suitable; Biophysical scores (criteria 1-4) are based on the analysis presented in Table 1-4 followed by expert consultation. **Scores are the highest for all micro-watersheds because of no variability in rainfall. ***Socioeconomic scores are given by the farmers during PRA exercise in FGD

3.4. Proposed Site for RWH Structure

The guidelines are available in the literature for selecting a suitable site of the runoff water harvesting (RWH) structure. Recently, both the biophysical and socioeconomic factors are considered for this purpose [18,40]. However, the biophysical factors are almost similar for all situations where the socioeconomic considerations are case-specific and the success of watershed management and development mostly depends on both. The most common criteria used for the selection of a site for the hydraulic structure were climate rainfall, hydrology, topography, land use, soils, and socioeconomic [30,41]. Accordingly, it was done in quantitatively for biophysical factors and qualitatively for socioeconomic factors (Table 6). The variation in socioeconomic factors in selecting suitable micro-watershed for RWH structure is much higher compared to that of bio-physical. The overall scores are the highest and identical in both MWS-2 and MWS-3 and followed by MWS-4 and MWS-1. Therefore, the former two watersheds are recommended for the RWH structure. Previously socioeconomic factors did not consider and integrated with biophysical factors in many of the assessments for micro-watershed development that caused the failure of the RWH project. Therefore, we used the Food and Agriculture Organization (FAO) listed six factors for the assessment of sites for soil water conservation [30]. It also emphasized on-ground validation and socio-economic factors to enhance the effectiveness of watershed [17]. We discussed with the farmers on the overall suitability scores of the watersheds and visited all the locations to validate the results, which indicated good coincidence with the suitability on the ground level for constructing the RWH structure.

4. Conclusions

Remote sensing and GIS techniques are capable of delineation, characterization, and suitable site selection to construct a RWH structure (dam). Sharing of knowledge and experience among the stakeholders is vital to address the questions relating to watershed site selection. For the success of watershed, local communities must show their openness to change and a clear interest in participating in the planning and implementation of the watershed activities. For selecting the appropriate site of constructing the RWH structure, the emphasis should be given on biophysical factors so that there would be no siltation in the water reservoir and also on socioeconomic factors to avoid social conflicts.

For conserving soil and managing the watershed in the future, the paper recommends the followings:

- *Jhum* cultivation and along the slope cultivation of any crop on steep and very steep hill slopes should be carefully practiced. Instead of seasonal cropping, horticulture, forest or tree plantation should be encouraged on steep and degraded lands;
- On gently and moderately slope, appropriate tree crops including fruit trees (jackfruit, mango, citrus, guava), quick-growing fuelled, fodder and pulpwood trees, and perhaps rubber, tea, and coffee can be considered for plantation;
- The exposure of bare soil needs to retain for the minimum possible time. Preferably, cover crops should be grown during the planting and establishment phases, or weed growth should be slashed and left as a mulch to cover the soil surface.
- As the horticulture sector is growing tremendously on the hill slopes, various orchards are preferable along the hill slope. For this, lifting water from the watershed reservoir to upper hill slopes to support irrigation is vital.
- Step terraces or bench terraces are appropriate wherever necessary. Roads and paths should follow hilltops or the contour wherever possible.
- Intensive agricultural practices such as the combination of high yielding crops with multipurpose trees could be appropriate with the supply of water from the reservoir.
- New high-value crops (coffee, cashew nuts, and spice crops) could be profitable.
- Community-based watershed management strategies need to be developed for maintaining the RWH structure, water reservoir, water flow channels and natural draining lines.

- This sort of initiative should be practiced and replicated in similar hilly areas so that sustained protection, preservation and production of the most vulnerable landmass can be achieved.

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