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Identification of rainwater harvesting sites using RS and GIS for Mann river in Maharashtra

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ABSTRACT

The soil and water are the prime input in crop production and serving as a continuous necessity for human survival. Therefore, it is imperative to assess and manage these resources *in-situ* to promote sustainable development on a watershed basis. Identification of suitable sites for rainwater harvesting (RWH) structures was carried out by weighted overlaying of the thematic layers. The weights assigned to slope, land use/land cover (LU/LC), soil, and rainfall are 33, 28, 21 and 18%, respectively. All the thematic layers were prepared in the geographic information system (GIS) environment in the raster format. Thematic layers (maps) were incorporated through rank / level by using Integrated Mission Sustainable Development (IMSD) guidelines. In this study, five thematic input layers of slope, LU/LC, hydrologic soil groups (HSG), drainage and rainfall were overlaid through weighted overlay for identifying the suitable sites for RWH structures in the Mann river catchment. A RWH suitability map with four classes was prepared for the watershed. The composite layer obtained from multiplication of the layer's weightage was averaged into four classes of highly suitable, suitable, moderately suitable, and poorly suitable. The suitable land for recharge facility creation like check dams, percolation ponds, continuous contour trench (CCT) and farm ponds were assigned to study area. The study area is having the full scope for the farm ponds, checks dams, percolation tank, and CCT. According to the IMSD guidelines 226 check dam, 11 percolation pond, 2075 farm pond and 8 CCT RWH structures site were identified. The estimated runoff volume could be stored at harvesting structures is 47554.40 ham that can be used for irrigation of agricultural / horticultural crops which would increase economy of the watershed.

1. INTRODUCTION

Rainfall is the lifeblood of rainfed farming, providing the primary source of surface and groundwater for agriculture. However, the distribution of this vital resource varies temporally and spatially, making it a critical factor for farmers (Satheeshkumar *et al.,* 2017). To optimize crop productivity, minimizing surface runoff and recharging groundwater by constructing suitable water harvesting structures are essential steps in watershed management. These actions are not only crucial for sustaining agriculture but also for supporting livestock production (Adham *et al.,* 2016). The Maharashtra is the most prominent state in the country receiving average annual rainfall has spatial variability and rainfall received in western Vidarbha region is 780 mm annually. It belongs to assured rainfall receiving zone and climate as semi-arid region. The Government had made effort through the different programme such as NWDPRA, *Jalyukt shiwar yojana*, etc. since long and very huge amount of work has been conducted in the region. But there is gap between the actual constructed RWH structures and need to be proposed in the field for effective harvesting the rainwater to increase irrigation area in the Maharasshtra. By doing so, only 17% area brought under irrigation, particularly in western Vidarbha only 4% area under irrigation. Hence, there need the proper planning, excitation and site selection for the RWH structure in the study area. The most common RWH structures are farm ponds, check dams, percolation tanks, and *nala* bunds adopted in watershed management programmes (Oweis *et al.,* 2012 and Gharde *et al.,* 2023). Identifying appropriate sites for these structures in the watershed is paramount for their efficient functioning. Currently, a significant portion of agricultural land remains unirrigated, and harnessing rainwater through strategic infrastructure can substantially increase water availability in these areas (Sivanappan, 2006).

Various methods and models exist for estimating the runoff potential form watershed. Recent years have witnessed a growing interest in applying remote sensing (RS) and GIS techniques for a range of hydrological and agricultural assessments. These tools have been employed to estimate surface runoff (Khan *et al.,* 2021; Chowdary *et al.,* 2013; Murugiah and Venkatraman, 2013), delineate RWH structure sites (Kolekar, *et al.,* 2017 and Ranade and Katpata, 2015), estimate soil erosion (Gelagay and Minale, 2016, Tithi Datta, *et al.,* 2023), and determine crop productivity (Maurya, 2011). LU patterns within a watershed profoundly influence runoff and evapotranspiration. Surfaces with vegetation that can intercept surface runoff and facilitate infiltration exhibit lower runoff coefficients (Chunale *et al.,* 2001). The information on LU/LC, along with their spatial distribution, plays a pivotal role in selecting curve numbers (CN) for hydrological assessments (Chowdary *et al.,* 2009; Neil and Devi, 2011, Gharde *et al.,* 2014). One of the promising techniques for site selection is weighted overlay analysis in the GIS environment, which allows the creation of composite maps indicating suitable sites for RWH structures (Singh *et al.,* 2009). The capacity of GIS to handle vast spatial and attribute data makes it a potent tool in hydrological modelling (Ramkrishnan *et al.,* 2009). In recent years, an integrated study of RS, GIS, and runoff modelling has emerged as a significant approach for targeting suitable sites for water recharging and harvesting structures (Ramkrishnan *et al.,* 2009). The weighted overlay analysis employed in GIS allows us to prepare composite maps, revealing ideal locations for RWH structures. These methodologies are instrumental in making data-informed decisions to maximize the impact of water resource management within the Mann river catchment. By employing advanced geospatial techniques, we aim to enhance water resource availability for agricultural and livestock production, aligning with the broader goals of sustainable development. This research not only contributes to the broader body of knowledge but also offers practical solutions to address water scarcity in the Mann river, Maharashtra, India. As we navigate a changing climate and growing demands on water resources, the novelty of this work lies in its potential to sustain agriculture, improve livelihoods, and support environmental conservation efforts in the region.

2. MATERIALS AND METHODS

Study Area

The Mann river catchment is situated in parts of Shegaon, Khamgaon, Chikhli, Mehekar, Balapur, Patur and Malegaon talukas of Akola, Buldhana and Washim districts, Maharashtra. Which is located between 20°54′59” to 20° 10'19”N latitudes and 76°18'51” to 76°59'31"E longitudes with average elevation 428 m above mean sea level (MSL). The location map of the watershed is given in Fig. 1. The study area is occupied predominantly by alluvium and deccan basalts provided by Ayers and Westcott (1994). The

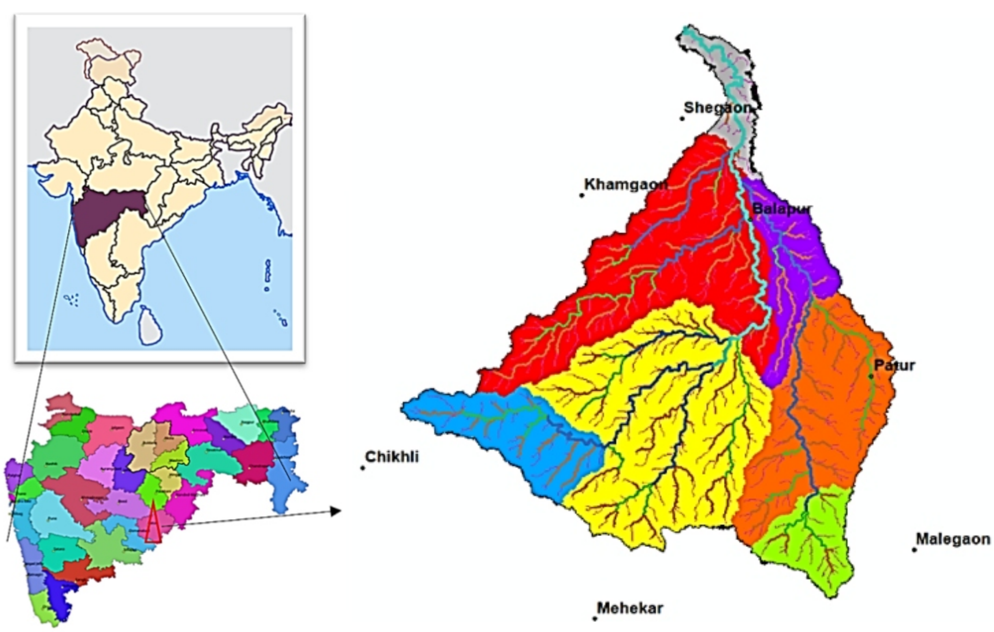

Fig. 1. Location of Mann river catchment

Mann river comes under semi-arid region with rainfall ranging from 750 to 1050 mm annually received during monsoon season (June to Sept). The river basin covered total of 2423 km^2 with moderate depth of soil of loamy and clayey in nature in the basin. The perimeter of the basin was 345.41 km. The geology data prevailed that, the basalt rock is parent material in the region prevent to easy ground water recharge.

Data Used

Sentinel-2 satellite images having 10 m resolution and Digital elevation Model (Fig. 2) having 30 m resolution were downloaded from https://earthexplorer.usgs.gov/. Satellite images of pre-monsoon (16th May, 2020), post-monsoon (14th Aug, 2020), winter (2nd Dec, 2020) and summer (17th March, 2021) season was used to prepare the LU/LC map of the catchment while the SRTM DEM with 30 m resolution was used in the slope map and drainage map generation. Soil map was collected from Maharashtra Remote Sensing Application Center (MRSAC), Nagpur for the region. The daily rainfall data of neighbouring 7 rain gauge stations (*i.e.* Shegaon, Khamgaon, Balapur, Patur, Chikhali, Mehekar and Malegaon) for the year 2001 to 2020 was downloaded from maharain portal (www.maharain.maharashtra.gov.in).

Rain Water Harvesting (RWH) Site Suitability Identification

The RWH site identification flow chart is given in Fig. 3, outlining brief steps to be followed for determining suitable sites. For identification of potential sites for RWH and runoff potential, individual thematic layers were assigned weightage and also their classes a rank depending on the influence of the parameter to rain water harvesting or their contribution to the output (Maina and Raude, 2016) and weighted overlay analysis was carried out by first converting all layers to raster format. For assigning the weight, the slope and LU/LC were assigned higher weight, whereas the soil texture and rainfall were assigned lower weight.

While assigning ranks to different inputs layers such as slope, the highest rank value was assigned for gentle slope and low rank value was assigned to higher slope. For LU/LC, high rank was assigned to waterbodies followed by forest land and agricultural land and low rank was assigned to barren land and settlements. For soil, clayey soil was assigned lower rank than other type of soils in study area. Loamy soils are in between sandy and clayey soils. As the sand or gravel allow maximum infiltration whereas in clay or fine-grained soils infiltration is less which causes surface runoff. For rainfall, higher rainfall was given more rank than lower rainfall value. As sites where more rainfall is occurs are favourable for the implementation of RWH structures. The classes with higher values indicated the most suitable

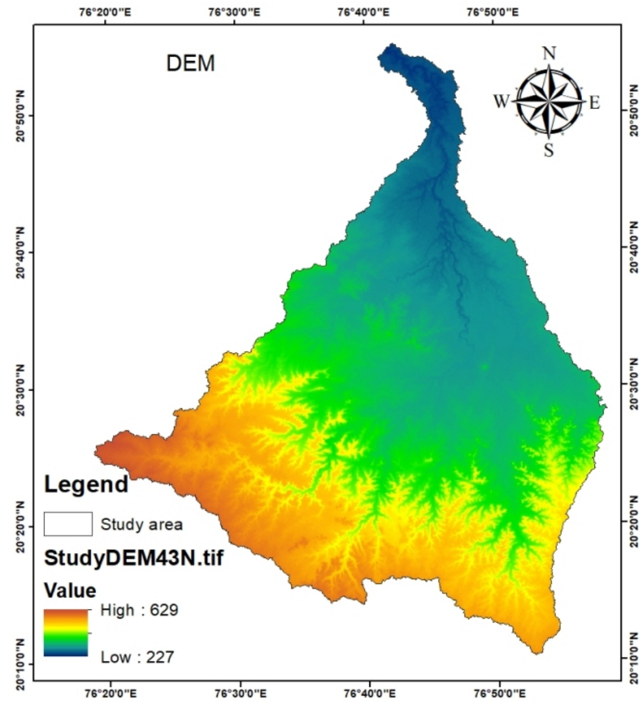

Fig. 2. SRTM digital elevation map of Mann river

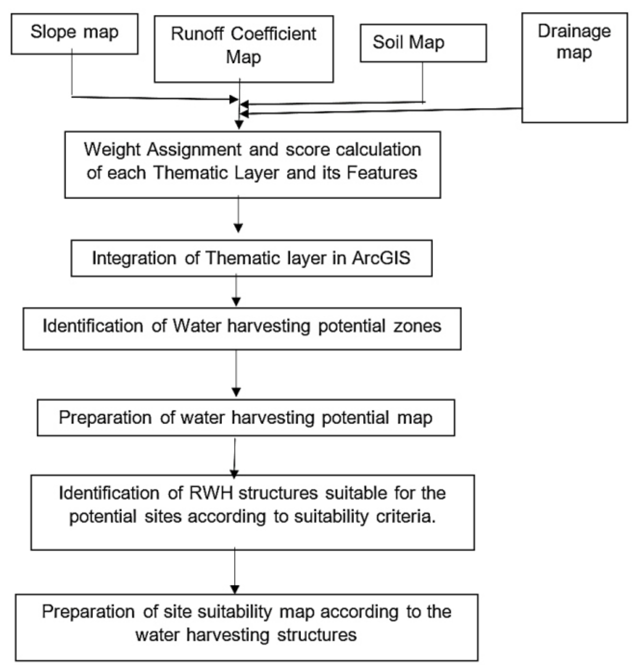

Fig. 3. Flow chart to identify the Suitable sites for RWH structures

sites. The final score was a product of rank and weightage where the site suitability was classified to be highly suitable, suitable, moderately suitable, or poor. The areas covered by each suitability category were calculated using the area tool. Further, the percentage suitability was estimated by considering each specific area and the total catchment area.

The parameters as rainfall, slope, soil type, runoff coefficient and drainage orders were used in the determination of spatial position of RWH structures within the most suitable areas (Ramkrishnan *et al*., 2009).

IMSD Criteria

Four water harvesting structures *viz.,* farm pond, check dams, percolation dam, CCT were considered in the study area to identify the site location apart from different structures. The IMSD criteria adopted for suitable sites selection for RWH structures is provide in Table 1. The site selection criteria comprise of land slope, soil permeability, drainage stream order and runoff coefficient were adopted to decide the site for selected rainwater harvesting sites (Kumar and Jhariya, 2016; Abdulla and Reeba, 2015). The result obtained for the selected structures site identified was physically confirmed using physical trace and data visualised in www.earth.google.com and check the accuracy of site identification.

3. RESULTS AND DISCUSSION

Different input thematic layers *i.e.* slope, drainage, hydrologic soil group map, LU/LC map and rainfall maps were prepared in GIS environment to determine the RWH potential and delineate the site of Mann river.

Slope Map

From the slope map (Fig. 4) of the study area and Table 1 and land slope classes are presented in Table 2. it is observed that, the study area has a complex terrain with undulations and irregular slopes. Most of the area of the basin has nearly level (0 to1%) to very gently (1 to 3%) sloping covering total area of 12.35 and 51.82%, respectively of the catchment and these slope range are very much suitable for selecting sites for rain water harvesting sites. 16.94% area belongs to gental slopping, 11.30% belong to moderate and least fall in steep (7.56%) not useful for RWH. It indiacates form the Fig. 4 that, majority of area suitable to moderate suitable for RWH sites.

Drainage Map

The drainage map of the study area is given in Fig. 5. It is observed that, basin has 5th order drainage network with dendritic in nature. It indicates that, the catchment has high runoff potential within short time of concentration because most of soil is clay with basalt trap geology. The drainage map was used in identification of potential sites for RWH structures.

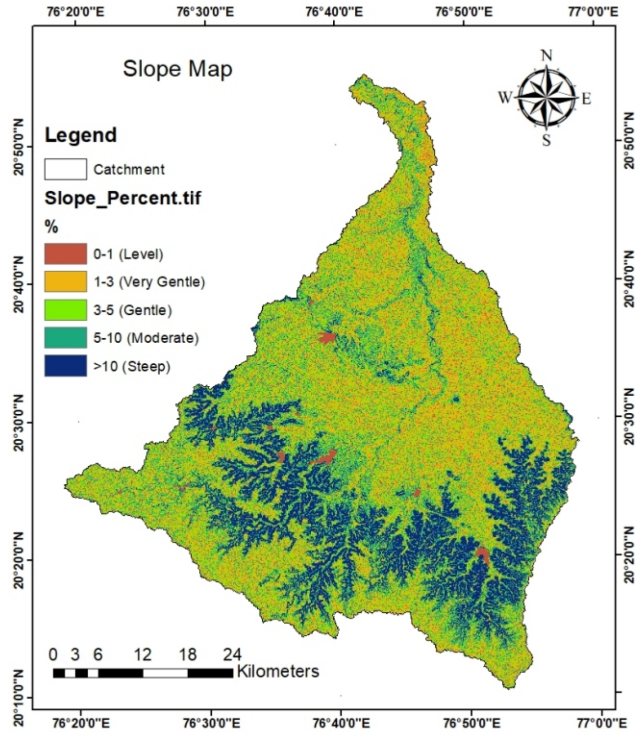

Fig. 4. Slope map of Mann river

Table: 2
Land slope classes of Mann

S.No.	Slope category	Slope (%)	Area (km^2)	Area (%)
1.	Level slope	0 to 1	299.27	12.35
2.	Very gently sloping	1 to 3	1256.12	51.85
3.	Gently sloping	3 to 5	410.52	16.94
4.	Moderately sloping	5 to 10	273.42	11.30
5.	Steep sloping	> 10	183.27	7.56
	Total		2422.6	100

Soil Map

The spatial distribution of hydrologic soil groups (HSGs) in Mann river catchment is given in Fig. 6 and soil hydrologic group are presented in Table 3. It is observed from Table 3 that catchment has two major HSGs *viz.,* HSG B and HSG D. The maximum area of the catchment comes

Table: 1
IMSD criteria for rainwater harvesting structures

S.No.	Water harvesting structure	Slope (%)	Permeability of soil	Runoff coefficient	Stream order
1.	Farm pond	0 - 5	Low	Medium / high	-
2.	Check dam	< 15	Low	Medium / high	2 - 4
3.	Percolation pond	< 10	High	Low	2 - 4
4.	CCT	10 - 25	High	Medium / high	1

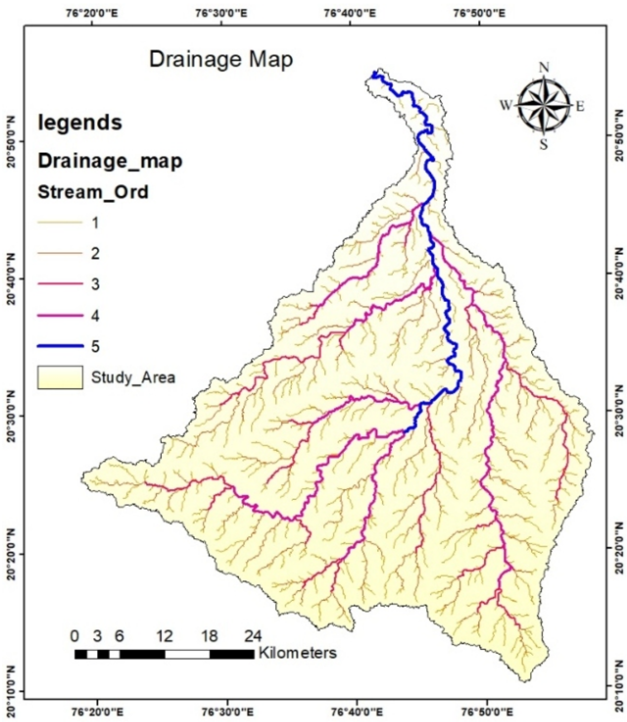

Fig. 5. Drainage map of Mann river

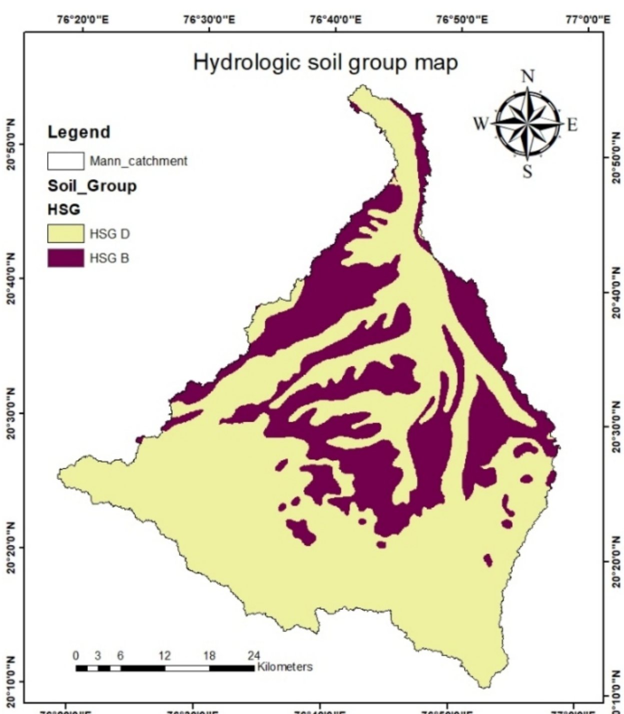

Fig. 6. Soil hydrologic group map

Table: 3
Hydrologic soil group classes

S.No.	Soil type	HSG	Area (km^2)	Area (%)
1.	Loamy	B	721.85	29.79
2.	Clay	D	1700.81	70.21
	Total		2422.66	100

under HSG D (*i.e.* 70.21%), whereas only 29.79% area comes under HSG B. The soil textural class of study area is clay to loam. As, RWH storage structures like farm pond and check dams are suitable in clay soil (HSG D) whereas the RWH recharge structures like Percolation pond and CCT are most suitable in loamy soil (HSG B). HSG D indicates the clay soil texture whereas HSG B indicates the loamy texture which produces low runoff as compared to clay soil. This HSG group indicates the soil producing high runoff with different vegetation cover and LU/LC characters (Subrahmanyam, 2009).

Land Use/Land Cover (LU/LC) Map

The LC/LC map of the study area is presented in Fig. 7 and summarized in Table 4. It is observed from Fig. 7 and Table 4 that, there are five major types of LU/LC class, namely Agricultural land (39.32%), Current fallow (28.13%), Urban settlement (16.75%), Forest, (14.31%), and Water Bodies (1.49%). This indicates that, the catch-

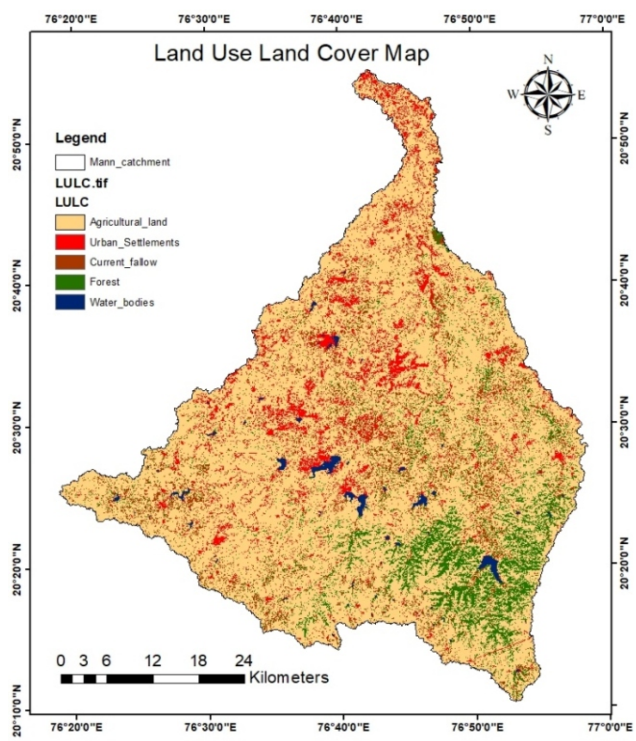

Fig. 7. Land use land cover map of Mann river

Table: 4
Land use/land cover classes of Mann river

S.No.	LU/LC class	Area (km^2)	Area (%)
1.	Water bodies	36.14	1.49
2.	Urban settlement	405.76	16.75
3.	Current fallow land	681.57	28.13
4.	Agricultural land	952.48	39.32
5.	Forest	346.71	14.31
	Total	2422.66	100

ment has the highest area under agriculture followed by current fallow land (28.13%).

Rainfall Map

In this study, raster map of rainfall obtained by using the average annual rainfall of 7 rainfall stations neighbouring to the study area and utilizing IDW interpolation method. Maximum, minimum and average annual rainfall of basin during the period of 2001 to 2020 was 1304.1, 385.1 and 766.7 mm, respectively (Table 5). The rainfall map of the catchment is given in Fig. 8. It indicates that, there is not much variation in rainfall over the river basin. The runoff potential of the catchment was estimated using spatial input data and SCS-CN methods. The estimated runoff potential of the catchment is presented in Fig. 9. The Mann river basin has runoff potential on volume basis is 57589.14 ha m.

Identification of Potential Sites for RWH

The resultant output of suitability of potential RWH sites for the Mann river basin was obtained by considering the IMSD criteria (Table 2) and applying weightages to the different parameters (Table 6) which is presented in Fig. 10. The RWH site suitability classes of Mann river basin is

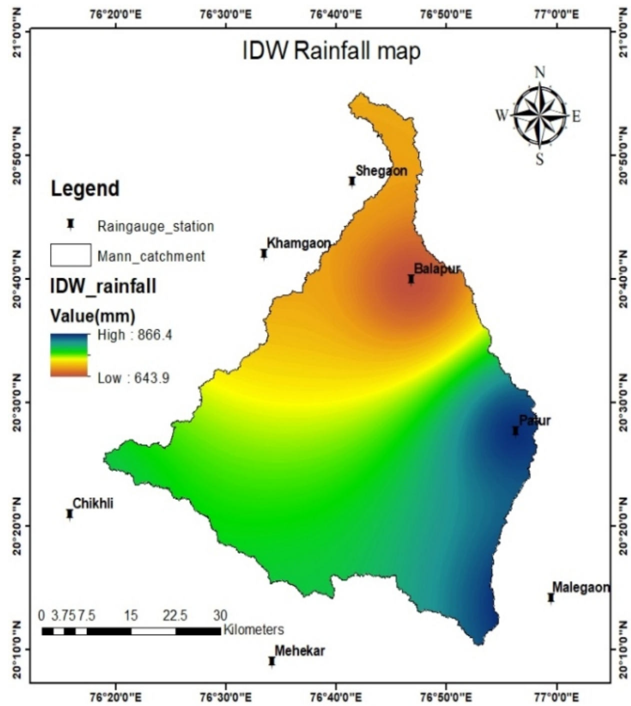

Fig. 8. Rainfall map of Mann river

Table: 5
Maximum, minimum and average annual rainfall of 20 years rainfall data

Stations	Maximum		Minimum		Avg.
	Year	Rainfall (mm)	Year	Rainfall (mm)	Rainfall (mm)
Balapur	2006	884.3	2004	448.6	643.9
Chikhali	2010	1192.1	2012	545	802.4
Khamgaon	2006	1028.1	2008	479	690.2
Malegaon	2013	1291	2014	601.5	884.1
Mehkar	2006	1202	2015	582.5	793.3
Patur	2002	1304.1	2011	454	864.3
Shegaon	2006	1048	2004	385.1	689
		Average of all station			766.7

Table: 6
Details of criteria for delineation of rainwater harvesting potential zones

S.No.	Criteria	Class/ units	Runoff generation rank	Rainwater harvesting / storage site	Weightage
1.	Soil	Loamy	1	1	0.21
		Clay	2	1	
2.	Slope	0 - 1%	1	5	0.33
		1 - 3%	2	4	
		3 - 5%	3	3	
		5 - 10%	4	2	
		> 10%	5	1	
3.	Land use/Land cover	Agriculture land	3	4	0.28
		Forest land	2	2	
		Urban settlements	5	5	
		Fallow land	4	3	
		Water body	1	1	
4.	Rainfall	High	1	1	0.18
		Moderate	2	2	
		Low	3	3	

given in Table 7. It is observed from the Fig. 10 and Table 7 that, the area is classified in four classes *viz.,* Highly suitable, moderately suitable, suitable and poor. The very less area (0.57%) comes under highly suitable criteria. The most of the area of Mann river basin was under the suitable and moderately suitable class which is 70.40% and 19.94% of the total area of catchment, respectively. It is clear that, more than 90% of catchment is suitable for RWH structured in the catchment. The IMSD criteria was adopted to delineate the RWH structures in the basin.

The proposed and existing number of RWH structures is given in Table 8. It is observed form Table 8 that, total RWH structured proposed in the Mann river basin are 2320 out of which 2131 are exist in the basins which are farm pond (2075), percolation ponds (11), check dams (226) and CCT 8 (980 ha). The additional 1089 new RWH structure *viz.,* farm pond (946), percolation ponds (11), check dams (124) and CCT 8 (980 ha) are need to be proposed for harvesting rainwater with full potential in the basin. The prepared RWH sites location map is given in Fig. 11.

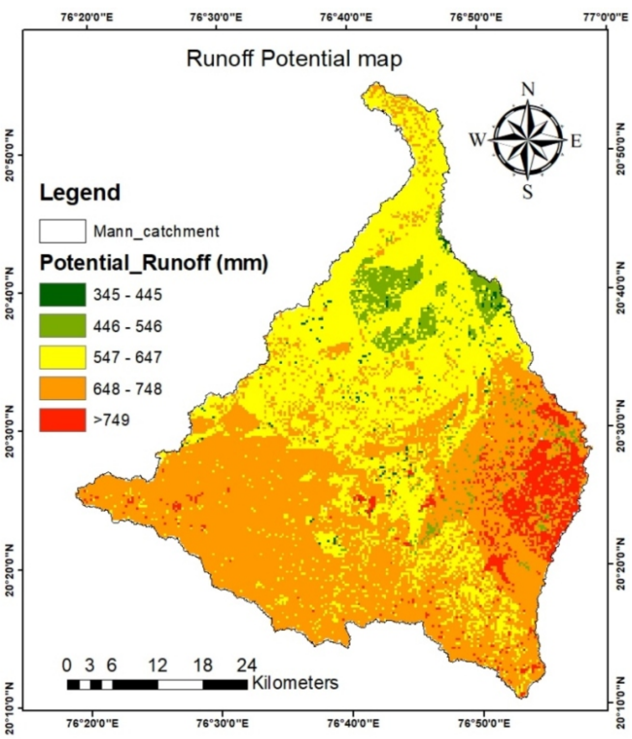

Fig. 9. Runoff potential map of Mann river

Farm Pond

The farm pond site suitability was estimated using IMSD guidelines for Mann river basin (Fig. 12). It is observed that, total suitable sites for farm ponds were 2075, which has potential to harvest rainwater 455.05 ha m in the catchment. The farmers of the basin were constructed farm pond through different govt. schemes were identified and located are presented in Fig. 13. The size of farm ponds were constructed under different schemes as 30 m × 30 m × 3 m and 20 m × 20 m × 3 m with side slope 1:1 for black cotton soils. Each farm pond can harvest rainwater 2193 m^3. The

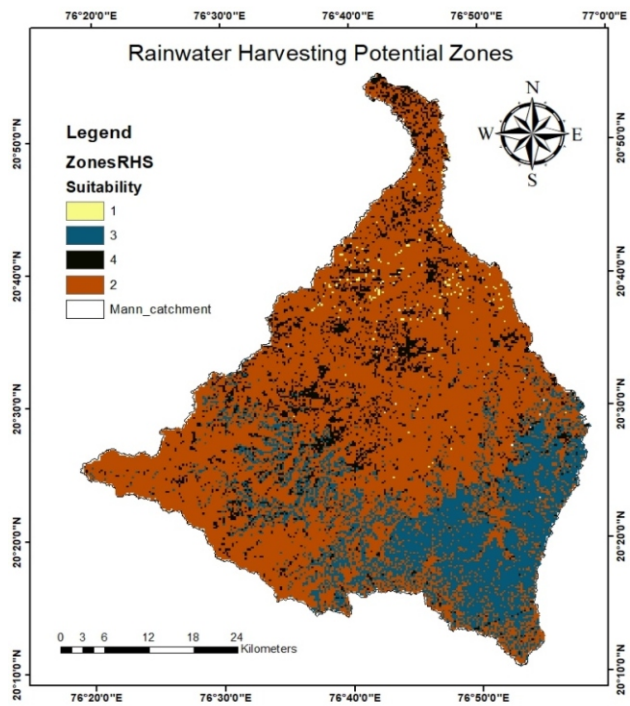

Fig. 10. Rainwater harvesting potential zones of Mann river

Table: 7
Rainwater harvesting site suitability classification of Mann river

S.No.	Suitability	Rank	Area (km^2)	Area (%)
1.	Highly suitable	1	13.72	0.57
2.	Suitable	2	1705.47	70.40
3.	Moderately suitable	3	483.03	19.94
4.	Poor	4	220.4	9.10
	Total		2422.62	100

Table: 8
Proposed and existing rainwater harvesting structures in the catchment

S.No.	RWH structure	Proposed number	Existing number	Additional number
1.	Farm pond	2075	1129	946
2.	Percolation pond	11	-	11
3.	Check dam	226	102	124
4.	CCT	8 sites (980 ha)	-	8 sites (980 ha)
	Total	2320	1231	1089

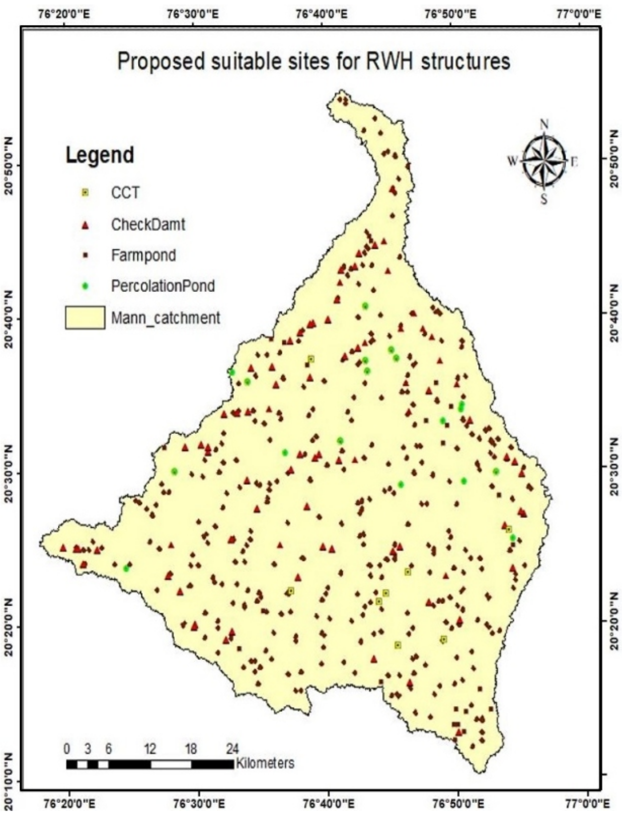

Fig. 11. Proposed suitable sites for rainwater harvesting structures

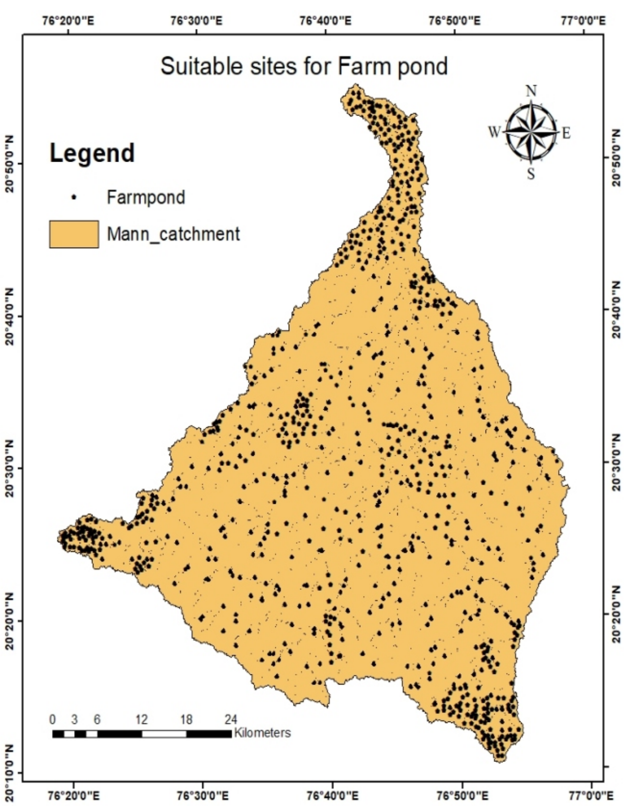

Fig. 12. Farm pond suitability site map Mann river

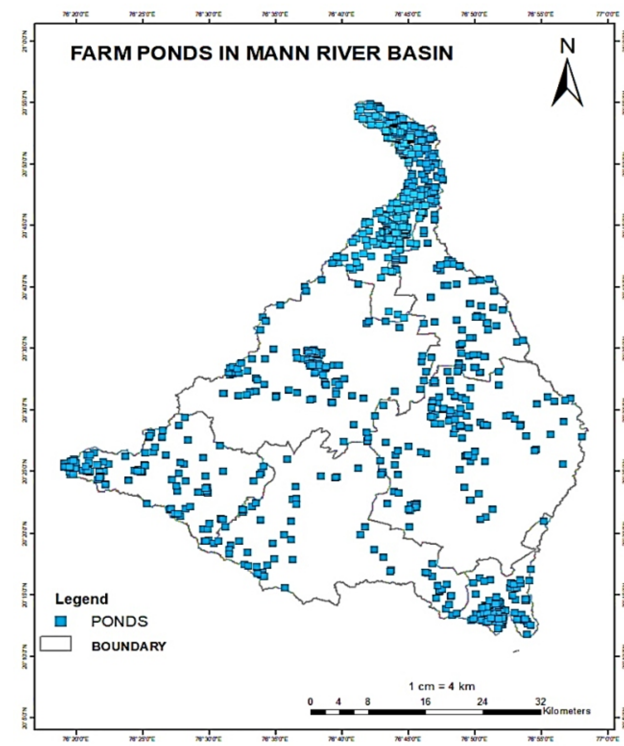

Fig. 13. Existing farm pond location map

additional farm pond proposed (946) under study will harvest runoff of 2074578 m^3.

Check dam (CNB's, KT weir and Minor dams)

The check dam suitability map is presented in Fig.14 and it is observed that, catchment has potential to construct the total 226 check dams according to IMSD guidelines, which has potential to harvest runoff amounting to 17340.78 ha m. whereas there were 102 check dam (KT weirs, minor dam and CNB) exist in the catchment which harvest total runoff amounting 7869.02 ha m. Hence, it is clear that, catchment has potential to construct additional 124 check dam at different location in the catchment. It will harvest rainwater additional total 9514.41 ha m.

Percolation Pond

The site suitability for percolation ponds were estimated in GIS environment using IMSD guidelines and suitability map is prepared is given in Fig. 15. There are 11 suitable sites for percolation pond were delineated in Mann river basin. These structures are more probably found suitable for ground water recharge and help in increase irrigation area. The proposed percolation ponds have the potential to harvest total runoff is 3300 ha m.

Continuous Contour Trenches (CCT)

The suitability for constructing CCTs in Mann watershed is given in Fig. 16. The 8 sites suitable for

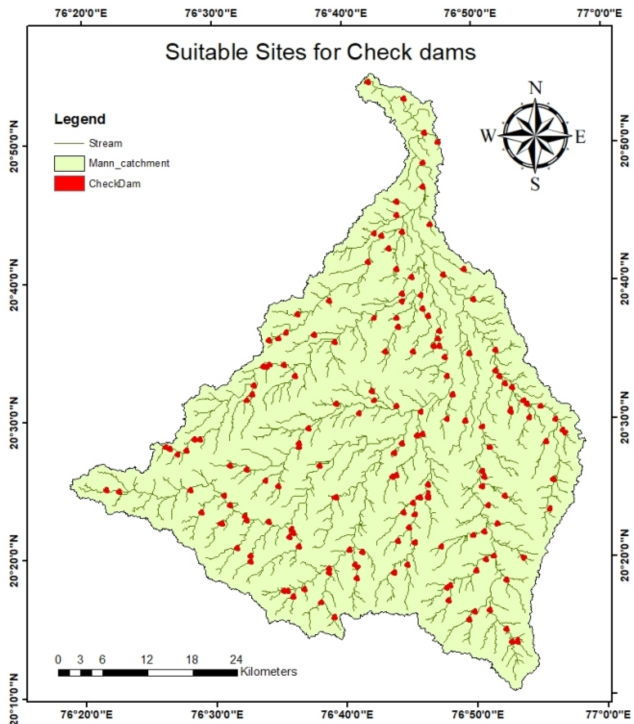

Fig. 14. Check dams' suitability site map of Mann river

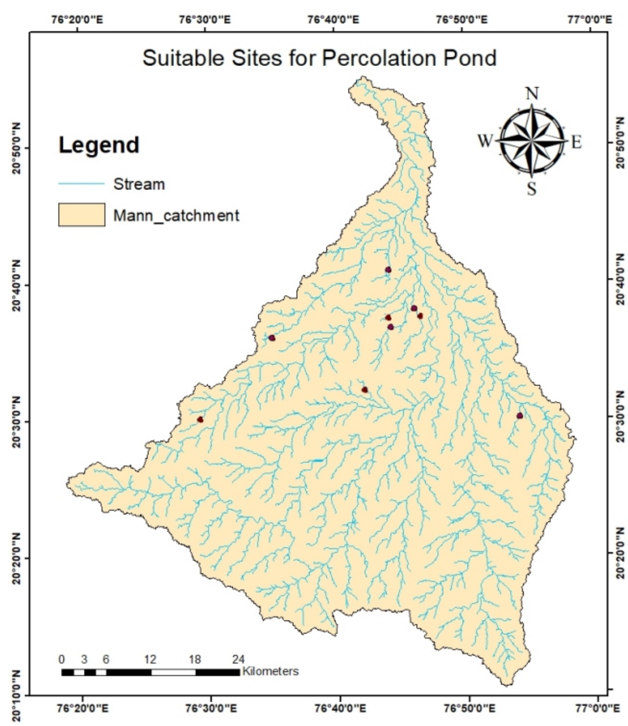

Fig. 15. Percolation pond suitability site map Mann river

construction of CCT are proposed under study. These sites could be proposed on total area of 980 ha. The CCT would harvest 270 m^3 rainwater per ha for this region. Hence, total water will be harvest 26458.57 ha m in the catchment.

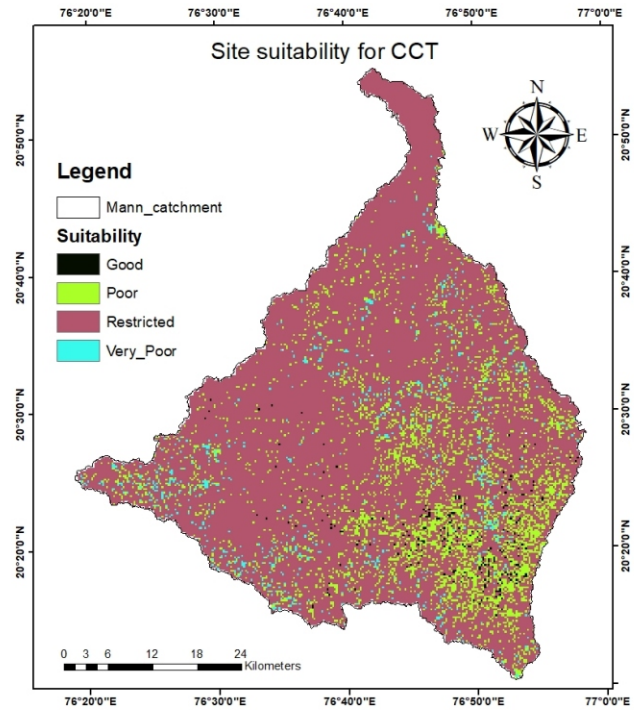

Fig. 16. Suitability site for CCT at Mann river catchment

4. CONCLUSIONS

The suitable delineated RWH structure sites in the catchment are check dams (226 sites), farm ponds (2075 sites), percolation ponds (11 sites) and CCT (8 sites). There is scope to construct additional 1089 RWH structure *i.e.* farm pond (946), check dam (124), and CCT (8 site on 980 ha area) in catchment. Hence, there is large scope to harvest the runoff for brought more area under irrigation, ground water recharging in the Mann river basin.

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