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Research Article

Determining Digital Elevation Model (DEM), Slope and Impact Analysis of Water Management Interventions in Coastal Seasonal Waterlogged Areas using Remote Sensing and GIS

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ABSTRACT

To improve water and land productivity of seasonal waterlogged areas of the coastal region, agroforestry based water harvesting system with improved waterlogged tolerant rice varieties were implemented in representative areas of Satyabadi and Kanas blocks of Puri district of Odisha. To assess the terrain, digital elevation model (DEM) and slope were analysed using remote sensing and GIS. From the DEM, it is revealed that elevation was less with respect to mean sea level which ranged between 3-19 m in Satyabadi block and 1-20 m in Kanas block of Puri district. The slope of the study area ranged between 0-5% in Satyabadi block and 0-3% in Kanas block, Puri. From ground assessment, net returns of Rs. 60000-80000 per ha with B:C ratio of 3.0-3.2 was obtained from the technology. The cropping intensity increased from 100% to 200%. To assess the impact of the technology over large entire (entire Sayabadi and Kanas block, Puri), remote sensing and GIS techniques were employed and remote sensing images (google earthpro) were compared before and after the technological interventions. Study revealed that before intervention (2005-06), only 45 ponds were available in entire Satyabadi block in 2003. After implementation of NICRA project (2012) through agro-forestry based farming system, numbers of farm ponds raised to 829 numbers in Satyabadi block in 2014 and to 1063 in 2018.

Key words: Digital elevation model, Slope, Waterlogged areas, Remote sensing, GIS

Introduction

The coastal areas with high concentration of population and economic activity known as the 'rice bowl' of the country but now is facing land degradation problems such as flooding, salinization, land erosion, sand casting, waterlogging due to impeded drainage etc. and thereby posing a serious threat to the food security. These areas are also vulnerable to multiple weather hazards like flood, drought, cyclone. The saucer shaped land forms, high rainfall (average 1500 mm) due to southwest monsoon (June-September), poor drainage condition make the coastal region susceptible to waterlogging and flood prone and area remains submerged for about 3-4 months (July-September) under water depths varying from 0.5-2.0 m. Thus, in one season (July to October), the coastal waterlogged areas remain under productive due to excess water, but in dry season (January to May), agriculture is not possible because of lack of water (Kar *et al.,* 2010; Kar *et al.,* 2012).

Recognizing the importance of improving water and land productivity of seasonal

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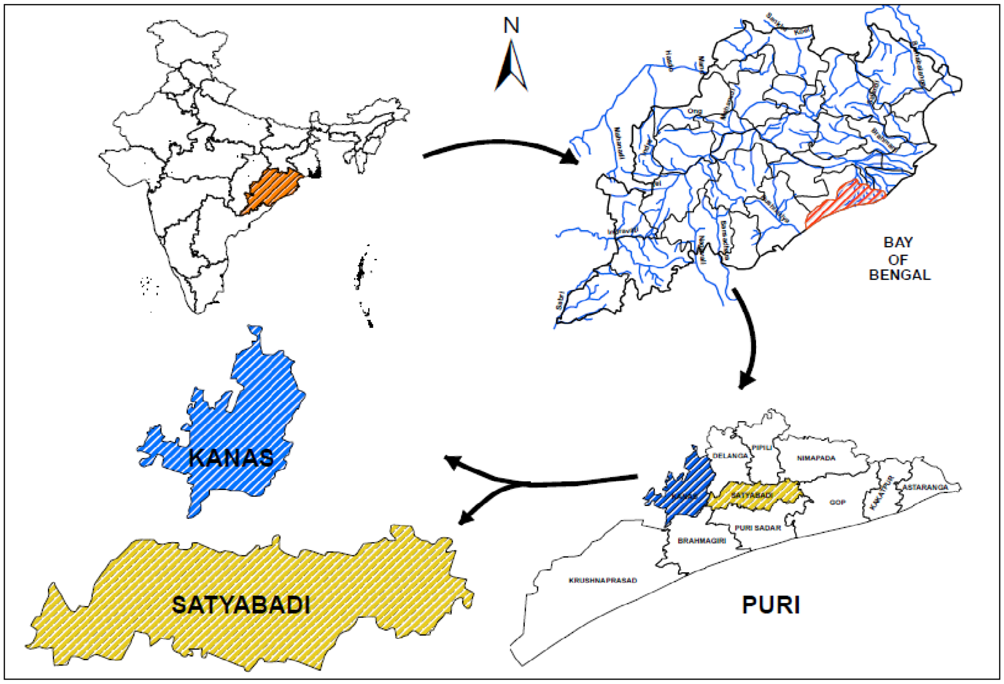

Fig. 1. Location map of the study blocks

waterlogged areas of the coastal region, agro-forestry based water harvesting system with improved waterlogged tolerant rice varieties were implemented in representative areas of Satyabadi and Kanas blocks of Puri district of Odisha.

DEM and slope analysis plays an important role in civil engineering, especially in the design of refuse disposal earth embankments, dams; highways, railroads, canals, surface mining, as well as many other human activities involving construction and excavations (Sharpnack and Akin, 1969; Skidmore, 1989; Tateishi and Akutsu, 1992; Seymour nd Cumming, 2004; Suganthi *et al*., 2010; Raut, 2016).

Materials and Methods

Study area

Two representative coastal waterlogged areas of Puri District of Odisha i.e. Satyabadi and Kanas were selected for the study (Fig. 1). The mean maximum temperature of the region is ranged from 33-37°C before flood (January—June). During flood period maximum temperature lowers to 31-32°C. In November and December maximum temperature drops to 24-27°C. Total seasonal rainfall of the area is about 1500 mm.

Digital Elevation Model (DEM)

Digital Elevation Model (DEM) is the digital representation of earth's topography with respect to any reference datum. DEM used to find terrain data, topographic attributes, and geo-morphometric parameters. To prepare the DEM elevation point data from Google earth were collected. The elevation point is then interpolated through IDW technique using spatial analysis extension of Arc GIS 10 software and Digital Elevation Model of two study blocks have been prepared.

Slope

Slope is the steepness or the degree of incline of a surface. It can be expressed either in degrees or as a percentage. From the prepared DEM, slope of the two study blocks has been prepared using surface tool of Arc GIS 10 software.

At every point in a DEM the slope can be defined as a function of gradients in the X and Y direction:

$$\text{Slope} = \arctan\sqrt{(fx)^2 + (fy)^2}$$

The key in slope estimation is the computation of the perpendicular gradients fx and fy. Different algorithms, using different techniques to calculate fx and fy yield the diversity in estimated slope. As mentioned above, from a gridded DEM, the common approach when estimating fx and fy is by using a moving 3 × 3 window to derive the finite differential or local polynomial surface fit for the calculation (Jones, 1998; Yun and Moon, 2001; Zhou and Liu, 2004).

Water management interventions

Water management in coastal waterlogged areas is given in Fig. 1. After studying the DEM and slope, rainwater harvesting system was constructed by taking 25-30% of the total field of a farmer, rest of the field was utilized for intensive cultivation with harvested water. The pond was dug in inverted trapezoidal shape with the side slope of 1: 1. The height of the bund was determined by the flooding depth. Study revealed that maximum flooding depth of 2.5 m occurred in saucer shaped flood prone coastal areas. Therefore, keeping a free board of 0.5m, maximum 3 m bund height was recommended for the water harvesting pond in flood prone coastal areas. The depth of pond ranged from 2-3 m depending upon the water requirement. Shallow depth was avoided as it favoured high evaporation losses. One or two inlet systems were designed and constructed on two sides of ponds for capturing outside floodwater into the pond.

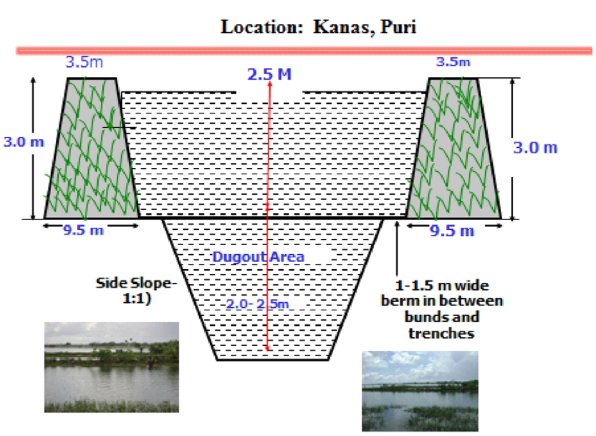

Fig. 1. Water management in coastal areas

The dyke of the pond was utilized to grow forestry species like *Acacia mangium,* Casuarina *etc.* which has great demand in the local market. The harvested water inside the structure was utilized for fish rearing and also to grow second crops (rice, vegetables) surrounding the structure by providing supplemental irrigation from harvested water. High yielding medium duration rice varieties like '*Konark*', '*Parijat*' etc. were found to be suitable to transplant from last week of December to first week of January after receding flood. To obtain more profit, vegetable crops like watermelon, okra, cauliflower, spinach, brinjal, ridge gourd were also recommended to grow as second crops with harvested water. Seasonal water use was computed as 545, 605, 495, 750 and 575 mm for watermelon, okra, spinach, brinjal and ridge gourd, respectively.

To assess the impact of the technology over large entire (entire Sayabadi and Kanas block, Puri), remote sensing and GIS techniques were employed and remote sensing images (Google Earthpro) were compared before and after the technological interventions.

Results and Discussion

Monthly rainfall probability analysis

Prediction of rainfall in different seasons is of paramount importance for raising crops successfully with high and stable yield. In this study monthly rainfall were predicted at 30%, 50% and 70% probability levels using different probability distribution. Because of high rainfall during southwest monsoon months and saucer shaped topography of the coastal region water accumulates on the surface. Winter or summer season rainfall is very less and uncertain and stagnant water starts to recede after November. Land becomes dry from January onwards and winter/ summer rainfall is erratic and uncertain. Sowing of high value crops without supplemental irrigation is not possible during winter/summer season. The monthly probable rainfall with different probability distribution functions are given in Table 1.

Table 1. Predicted and observed monthly rainfall (mm) of Puri district

Months	Normal			Lognormal			Log Pearson			Extreme Values			Weibulls		
	30%	50%	70%	30%	50%	70%	30%	50%	70%	30%	50%	70%	30%	50%	70%
Jan	25.8	12.9	-	-	-	-	-	-	-	21.7	8.8	-	9.8	2.6	0.0
Feb	29.0	16.6	3.9	-	-	-	-	-	-	25.1	12.7	2.4	20.1	8.0	0.7
Mar	34.6	20.9	7.0	-	-	-	-	-	-	30.2	16.6	5.4	30.3	8.1	0.8
Apr	36.7	23.9	10.9	-	-	-	-	-	-	32.6	19.9	9.3	31.7	16.6	7.5
May	105.9	56.7	6.6	-	-	-	-	-	-	90.2	41.2	0.5	60.7	32.0	22.4
Jun	204.7	161.1	116.7	185.2	142.0	108.4	184.8	141.6	108.1	190.7	147.3	111.3	186.5	150.8	105.2
Jul	342.3	283.9	224.5	321.4	265.3	218.2	317.7	261.3	216.0	323.6	265.5	217.3	334.9	261.2	216.0
Aug	375.2	318.7	261.0	362.8	299.6	246.4	370.8	309.9	253.3	357.1	300.8	254.0	366.8	328.8	274.5
Sep	261.4	217.7	173.2	255.3	198.9	154.3	269.5	226.1	176.0	247.4	203.9	167.8	255.7	222.3	174.0
Oct	201.7	133.0	63.0	146.3	84.2	48.0	156.3	93.6	52.3	179.7	111.3	54.4	134.6	106.3	62.0
Nov	73.4	41.9	9.8	-	-	-	-	-	-	63.3	32.0	5.9	43.5	15.8	2.0
Dec	10.0	4.3	-	-	-	-	-	-	-	8.2	2.5	-	0.8	0.0	0.0

DEM

Digital Elevation Model (DEM) is the digital representation of earth's topography with respect to any reference datum. DEM used to find terrain data, topographic attributes, and geo-morphometric parameters. For making DEM elevation point data from Google earth was collected and using spatial analyst extension of Arc GIS 10 software, Digital elevation model of two study blocks were prepared. From the DEM, it is revealed that elevation was less with respect to mean sea level which ranged between 3-19 m in Satyabadi block and 1-20 m in Kanas block of Puri district. (Fig. 2,a, b)

Slope analysis

Slope is the steepness or the degree of incline of a surface. It can be expressed either in degrees or as a percentage. From the prepared DEM, slope of the two study blocks has been prepared using surface tool of Arc GIS 10 software. The slope of the study area ranged between 0-5% in Satyabadi block and 0-3% in Kanas block, Puri (Fig. 3, a,b).

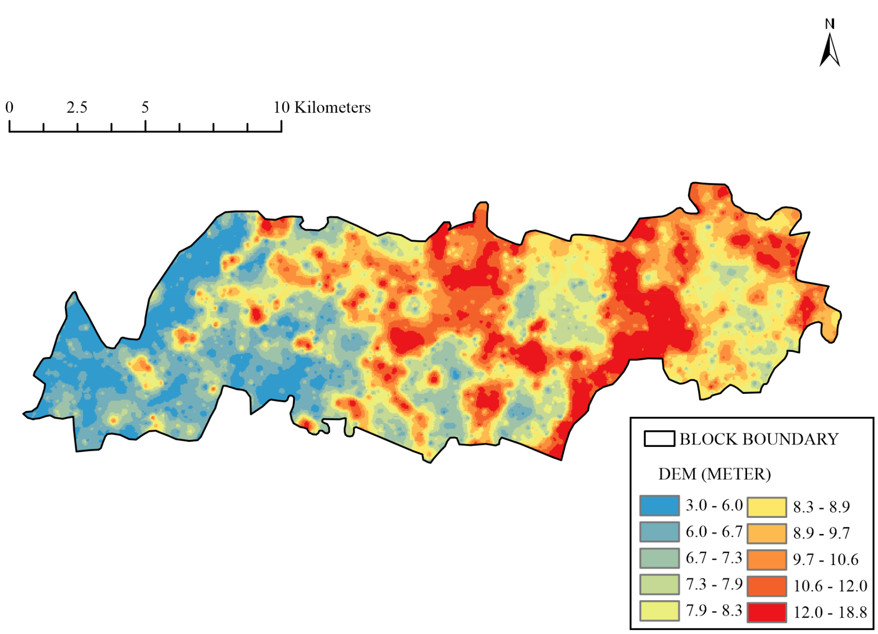

Fig. 2a. DEM of Satyabadi block, Puri, Odisha

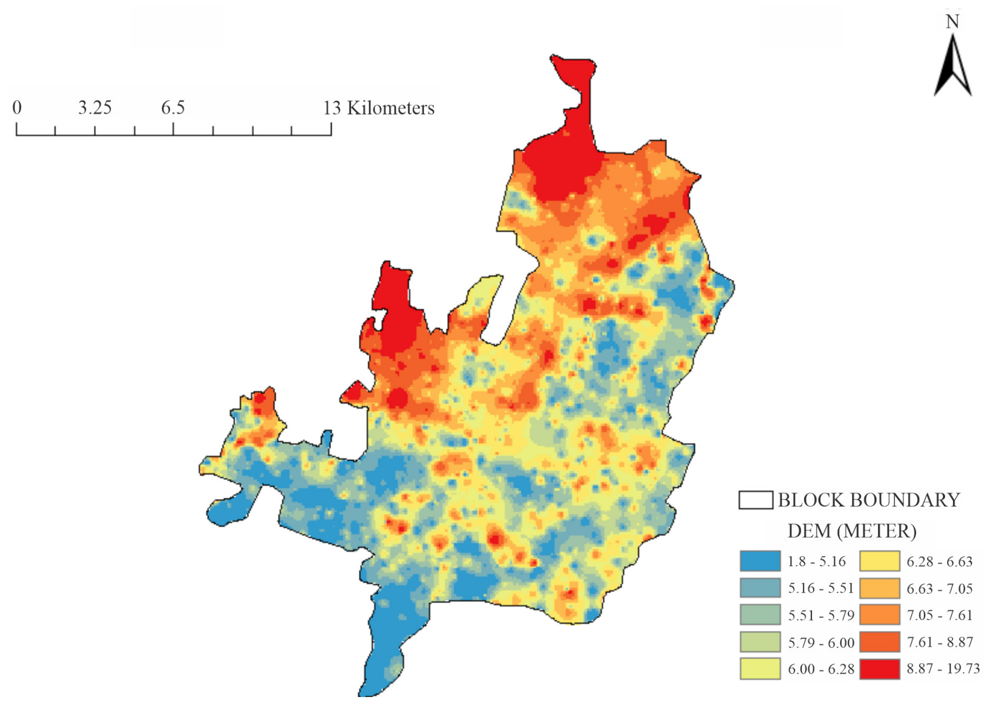

Fig. 2b. DEM of Kanas block, Puri, Odisha

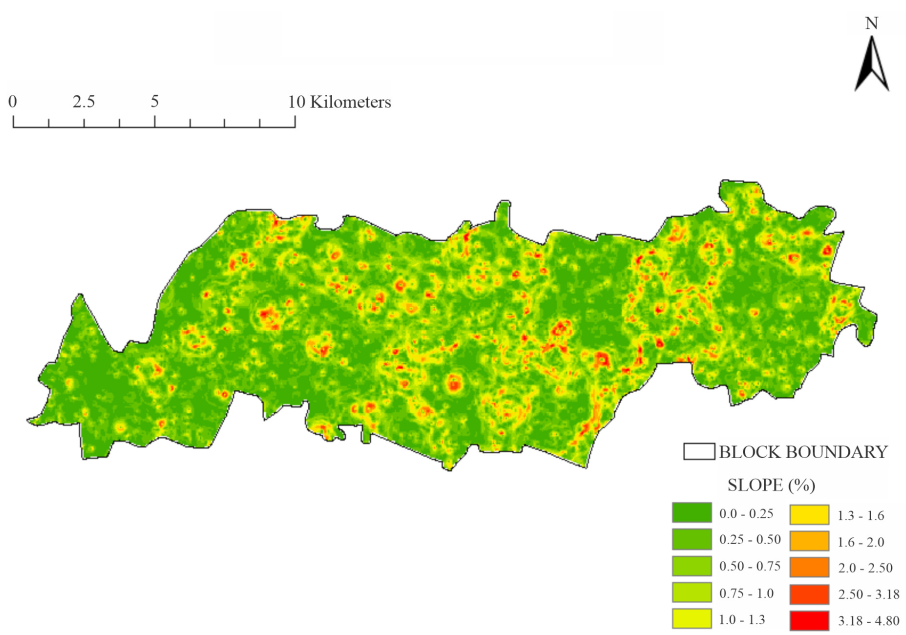

Fig. 3a. Slope map of Satyabadi block, Puri, Odisha

Ground assessment of impact of technology

The technology of "agro-forestry based water harvesting system" was found to be economically viable, ecologically suitable and sustainable in the waterlogged areas. Larger number of farmers of Satyabadi and Kanas blocks of Odisha have adopted the technology. The success story of the technology was also heighted by national and regional media and many number of training and awareness programme were also organized to disseminate the technology to wiser group of farmers.

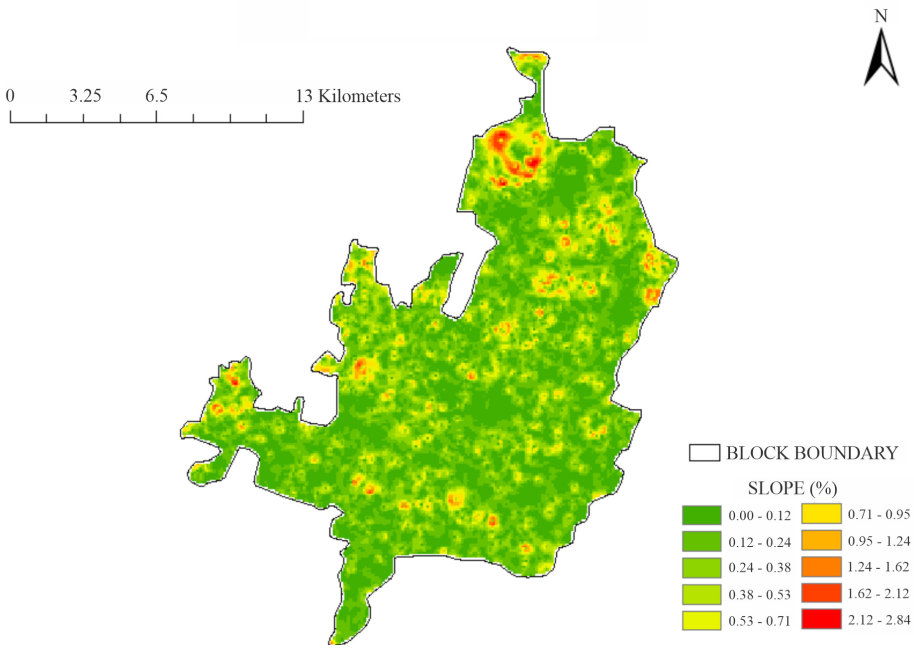

Fig. 3b. Slope map of Kanas block, Puri, Odisha

Table 2. Net returns through agroforestry based water harvesting system

Farmers	Pond dimension (m^3)	Farming area (pond + land cultivated) (ha)	Gross income from field crops (Rs.)		Gross income on dyke forestry (Rs.)	Gross income fromFish (Rs.)	Gross total income (Rs.)	Net income (Rs) from the area	Net income (Rs/ha)	Net water productivity (Rs/m^3)
			Kharif	*Rabi*						
FI	34×24×2.1	6428	18678	32658	35000	23000	90658	63461	98725	6.17
F2	34×24×2.3	6558	18528	32829	42000	24900	99729	69811	106451	6.65
F3	22×16×2.1	5602	17325	30293	28000	21000	79293	55505	99080	6.19
F4	32×24×2.1	5548	15774	27581	24000	23800	75381	52766	95109	5.94
F5	32×24×2.3	10199	27350	53474	41000	38500	132974	93082	91265	5.70
F6	32×24×2.3	12928	40128	68947	48000	35000	151947	106363	82273	5.14
F7	40×30×2.5	16400	50160	87704	59000	50000	196704	137693	83959	5.25
F8	40×30×2.5	15400	44020	81934	52000	80000	213934	149754	97243	6.08
F9	40×30×2.5	16840	46920	90243	44000	85000	219243	153470	91134	5.70
F10	40×30×2.5	17720	54516	93668	53000	50000	196668	137668	77691	4.86

After almost five years of technological intervention, an attempt has been made during June-August, 2019 to assess the impact of technology and benefit accrued from the same from the project as well as from outside project areas through questioner survey. Study revealed that after adopting the technology by different farmers, net returns of Rs. 60000-80000 per ha with B:C ratio of 3.0-3.2 was obtained from the technology. The cropping intensity increased from 100% to 200%. Besides increasing the cropping intensity and land productivity, fish and forest species of agroforestry based water harvesting system enhanced the water productivity from Rs. 1.10/m^3 (existing mono-cropping) to the range of Rs.4.08-6.65/m^3 (Table 2). From water chestnut and *Calamas cultivars* Rs. 19,000/ha and Rs. 35,000/ha net returns respectively were obtained

Assessment of impact of technology using remote sensing and GIS

To assess the impact of the technology over large entire (entire Sayabadi and Kanas block, Puri), remote sensing and GIS techniques were employed and remote sensing images (google earthpro) were compared before and after the technological interventions. Study revealed that before intervention (2005-06), only 45 ponds were available in entire Satyabadi block in 2003. After implementation of NICRA project (2012) through agro-forestry based farming system, numbers of farm ponds raised to 829 numbers in Satyabadi block in 2014 and to 1063 in 2018 (Fig. 4,a,b,c).

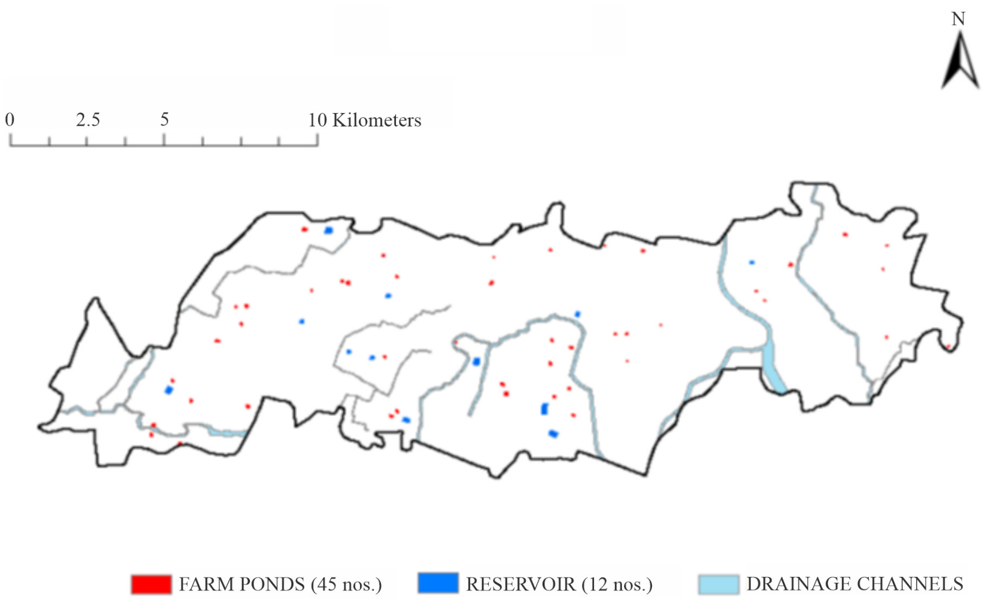

Fig. 4a. Number of farm pond in Satyabadi block in December, 2003

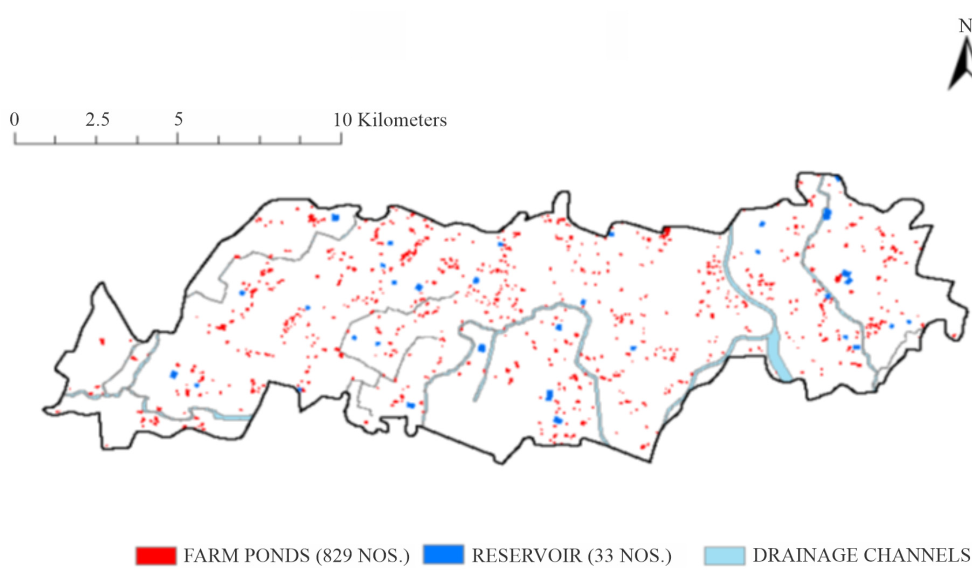

Fig. 4b. Number of farm pond in Satyabadi block in February, 2014

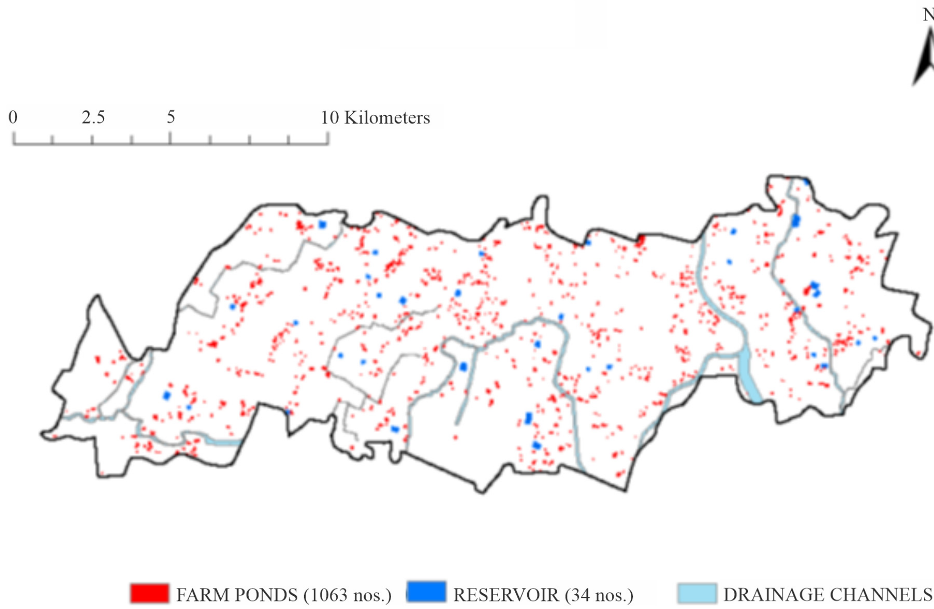

Fig. 4c. Number of farm pond in Satyabadi block in December, 2018

Conclusion

The technology of "agro-forestry based water harvesting system" was found to be economically viable, ecologically suitable and sustainable in the waterlogged areas. Larger number of farmers of Satyabadi and Kanas blocks of Odisha have adopted the technology. The success story of the technology was also heighted by national and regional media. Besides, enhancing productivity, profitability and cropping intensity, the technology has potential to build up climate resilient agriculture. The remote sensing and GIS technology are found to be highly useful for sloe and DEM analysis, prerequisite of terrain assessment. Google earthpro remote sensing images can be effectively employed for impact analysis of water management interventions.

References

Jones, K.H. 1998. A comparison of algorithms used to compute hill slope as a property of the DEM. *Computers & Geosciences* **24(4)**: 315-323.

Kar, G., Ashwani Kumar and Sahoo, N. 2012. Deep water rice production as influenced by time and depth of flooding in east coast of India. *Archives of Agronomy and Soil Science* (Taylor and Francis), **58(6)**: 573–592

Kar, G., Sahoo, N. and Ashwani Kumar. 2010. Deep water rice and pond based farming for higher productivity of waterlogged areas . Research Bulletin No 48 Published by Director Water Technology Centre for Eastern Region, Bhubaneswar-23, Orissa, India, 32p.

Raut, S., Kar, G. and Sahoo, N. 2016. Study of waterlogging and drainage in relation to soil in coastal Odisha using remote sensing and GIS. *Journal of the Indian Society of Coastal Agricultural Research*, **34(1)**: 156-57.

Seymour Michael and Cumming. 2004. Updating DEMs using RADARSAT-1 data. *Canadian Journal of Remote Sensing*, **30(6)**: 927-942.

Sharpnack, D.A. and Akin, G. 1969. An algorithm for computing slope and aspect from elevations. *Photogrammetric Survey* , **35**: 247-248.

Skidmore, A.K. 1989. A comparison of techniques for calculating gradient and aspect from a gridded digital elevation model. *International Journal of Geographical Information Systems* **3(4)**: 323-334.

Suganthi, S. and Srinivasan, K. 2010. Digital Elevation Model generation and its application in Landslide studies using Cartosat-1. *International Journal of Geomatics and Geosciences*, **1(1)**: 1-10.

Tateishi, R. and Akutsu A. 1992. Relative DEM production from SPOT data without GCP. *International Journal of Remote Sensing*, **13(14)**: 2517-2530.

Yun, Sang-Ho and Moon, W.M. 2001. Leanment extraction from DEM using drainage network Geoscience and Remote Sensing Symposium. *IEEE International* **5**: 2337-2339

Zhou, Q.M. and Liu, X.J. 2004. Analysis of errors of derived slope and aspect related to DEM data properties. *Computers & Geosciences* **30(4)**: 369-378.

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