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Performance Assessment of Medium Water Storage Infrastructures using Geo-Spatial Techniques; Satara District, Maharashtra A Case Study

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Abstract*: The sustainable water availability in a semi-arid region is achieved by construction of permanent/temporary water storage systems and distributary networks. Their functional status is crucial for regional development. The objective of this study is to develop methods in evaluating the functional status of water storage supply infrastructures. In addition to the thematic map, orbitalsatellite (IRS) images and ground based information were used in assessing the storage capacity and physical conditions of medium water storage structures of Krishna River basin in the Satara district of Maharashtra in India. Assessment of Water infrastructure condition (WIC) was carried out based on Reservoir Storage Efficiency (RSE) and canal conditions (CC) were developed. The storage and distribution systems are functioning at 38 to 68% of their capacity.

***Keywords*: Krishna River, semi-arid region, water storage capacity, sustainability of water, water infrastructure condition (WIC) reservoir storage efficiency (RSE), canal conditions (CC).**

I. INTRODUCTION

The deficit of water availability is calculated based on the supply and demand of a region and expressed as stress, scarcity and vulnerability. The fresh water availability in semi-arid and arid regions is subjected to situations such as: 1) demand exceeds availability, 2) non-availability of water infrastructure or poorly managed systems, 3) ground water extraction exceeds recharge, leading to quality and quantity issues, 4) uncertainty of rainfall amount, time and place, 5) drought situations etc. The climate change could adversely affect the stress conditions. Many countries have developed their water infrastructures (storage, distribution and agriculture / drinking water) towards their development. Ground water as supplementary source in the water supply system has become the easy target in meeting the additional water demands. This has led to fall in the ground water level. Surface water (as a supply source) availability in the tropical monsoon region depends on the rainfall amount and storages. A detailed analysis of supply (in terms of storage) and demand scenario is essential. Performance of irrigation system is focused on internal processes of irrigation schemes. It is related to the management objectives such as the area irrigated, crop patterns and distribution and delivery of water (Bos et al. [1]). Temporal irrigation performance assessment of Menemen, Turkey was evaluated by case study by Kukul et al. [2]. These process indicators have been developed to assess the quality of operational performance. The reliability, resilience and vulnerability were estimated in the risk assessments of water resources systems by Kjeldsen and Rosbjerg [3]. Jain [4] used the behaviour of statistical indices for performance assessment of a reservoir. Vogel et al. [5] applied the storage– reliability–resilience–yield relations for over-year water supply systems. Molden and Gates [6] have proposed nine external and other comparative indicators which will allow for comparison between countries and regions, different management types and environments, and for assessment over time of the trend in performance of a specific irrigation scheme. These comparative indicators have been used to assess the temporal and spatial variations of agricultural water use, environmental and financial performances of irrigation systems (Kloezen and Garce's-Restrepo [7]). Very few of the studies have evaluated the impacts of management interventions, e.g. irrigation management transfer. There is a need for the existing water infrastructures assessment and plan for the future.

II. OBJECTIVE

The objective of this study is to evaluate the water infrastructures (reservoir/tanks and canals/other distributaries) aiding in the water supply on a river basin scale. River basin located in the semi-arid region, having rain-shadow region as their catchment, several water infrastructures – reservoirs, canal system, lift irrigation system of irrigation and natural tank has been selected. One among the tributaries of Krishna River, India – Krishna River basin has been identified for this study.

III. MATERIALS AND METHOD

Meteorological information such as rainfall, temperature and humidity was collected from the ten rain gauge stations (point source), terrain, drainage network and water infrastructure information (Spatial information) were collected survey of India Topographic sheets (contour and elevation), Indian Remote sensing satellite images (vegetation, surface water bodies, canals) and the Census of India. ArcGIS 9.3 was used in digitization and integration of spatial and point information and creates a geospatial data base. Extensive field visits were made in the physical assessment of reservoirs (sedimentation, Embankment, sluice gate), canal conditions and benefits (crop area, constraints).

IV. STUDY AREA-KRISHNA RIVER BASIN AND SATARA DISTRICT

A. Krishna River Basin

Below Wai, the valley widens out, and on the right bank, is joined by the leading tributaries Kudali Vena, Urmodi and Tarali. The valley floors are well-cultivated and well-populated, the streams draining in the valleys have carved out small amphitheatres into the sides of the intermediate ridges. The sides of these ridges are generally bare but carry poor grass and scrub, and are usually given to grazing, and some of the tops carry the ancient fortified sites like Vairatgad.

Fig. 1 Location of Krishna River Basin (Source: www.mapsofindia.com)

Below Wai the main river valley of Krishna develops a fertile ribbon, well-cultivated and densely populated. The valley proper is deeply entrenched and meanders, old river terraces, and intense gully erosion introduce considerable local variation in landscape and land use. Krishna river basin has an economic importance in Western Maharashtra.

B. Satara District

Satara, the seat of Chhatrapati dynasty of Maharashtra, is the highest sugar--producing district in the State. The district has taken a quantum leap in dairy production and development. The massive Koyana hydroelectric project or the dams at Dhom, Kanher, Urmodi and Tarali have made the district fertile though some talukas are still awaiting irrigation.

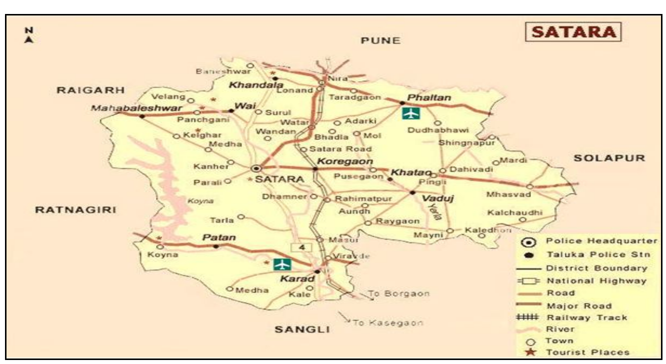

Fig. 2 Satara District Map (Source: www.mapsofindia.com)

Rainfall is of prime importance as a factor considerably influencing the agricultural economy of the district. It determines the pattern of crops taken in the district as well as the performance of various agricultural operations. The extent and spacing of rainfall perhaps explain the different cultivable practices obtained in varying degree; between the regions. The rainfall varies in different parts of the district, depending upon their nearness or otherwise to the mountains. 'Thus, the western part has a high rainfall on account of its mountainous topography, while the eastern part of the district has a low rainfall. The rainfall commences in the month of April and continues till the end of September. However, the precipitation of monsoons proper begins by the end of the first week of June. The average rainfall for the district as a whole except Mahabaleshwar taluka comes to about 33", whereas for Mahabaleshwar taluka, the average is about 260". Usually sowings are completed during the first and the second weeks of June. In November-December there is a shower known as Mango-shower which is beneficial to the agriculturist for his *rabbi* crops.

V. ASSESSMENT OF WATER INFRASTRUCTURES

Water resources' engineers employ reliability, resilience and vulnerability indices, in assessing the performance of a reservoir. In semi-arid regions, Evaporation losses are high and if these are ignored, one may overestimate the reliability of the reservoir by up to 10%. Multi-criterion decision making methods have been developed and applied in river basin planning (Srinivasa Raju [9]). Water infrastructures are evaluated based on their functional potential (physical condition), effectiveness (storage or conveyance loss), and benefits in decision making processes (existing system improvement or new system) using multi-criteria approach. *Reservoir storage efficiency* (RSE) is assessed by – sedimentation (S1) (water storing capacity), condition of embankment (E1) (potential leakage), and sluice gate operation (SG1) (water release). They were grouped into five classes – maximum value indicates the intense difficulty in operation (sustained operation is not smooth) and minimum value opines the easiness (continued dependability). They were ranked depending on their contribution in the sustainable operation. It was observed from the inventories on the reservoirs (about 75) and canals in the Krishna river basin and adjoining areas that 40% of the reservoir systems are not effective due to sedimentation (S1), 35% due to weak/damaged embankments (E1) leading to leakage and 15% due to condition of the sluice gate operations (SG1). Non-function of reservoir is the cumulative contribution from said factors. Weightage to individual parameters in water storing was assigned. The observed degraded condition of reservoir is shown in fig. 3.a. The observation and information from the reservoir was used in assigning their functions. Table 1 shows the physical condition assessment of reservoirs.

$$RSE = \Sigma\,(S1rank \times weightage) + (E2\ rank \times weightage) + (SG1\ rank \times weightage) \quad \ldots\ldots\ldots\ldots (1)$$

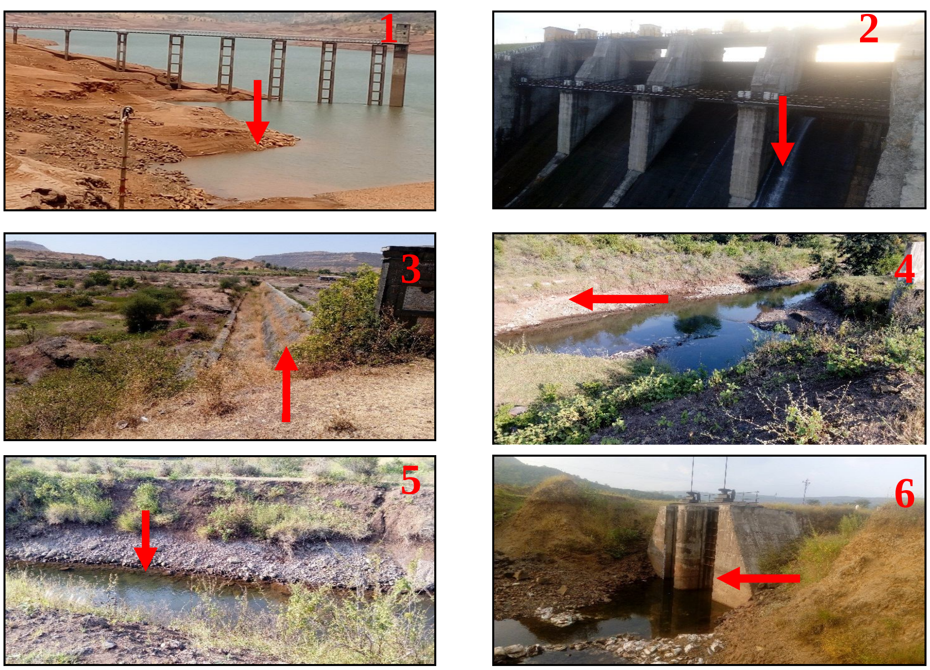

Fig 3 a) *Reservoir conditions*- 1. Sedimentation, 2. Leakage through spillway gate,3. Cracks and tree growth on embankment. b) *Canal conditions*- 4. Poor canal lining status and vegetation growth, 5. Bank collapse 6. Poor conditions of weirs on canal length.

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The stored water is conveyed / transported to the agriculture plots through lined or unlined *open canals*. The problems associated with free water movement in canals are – bank collapse (BC), sediment deposition and scouring of beds etc.; water pools (WP) (mainly attributed to sediment deposition); weed growth within the canal; seepage across the embankment and weed growth (WG). The observed degraded condition of reservoir is shown in fig. 3.b. The ground based information collected was used in ranking and weightage to individual parameters (similar to reservoir assessment). The observation and information
(table 2) from the canal site was used in canal condition (CC).

TABLE I PHYSICAL CONDITIONS ASSESSMENT OF RESERVOIRS

Parameters	**Class**	**Rank**	**Weightage**
Sedimentation Level (with reference total capacity) (S1)	<10 %	1	50
	11-30 %	2	
	31-50 %	3	
	51-70 %	4	
	>71 %	5	
Embankment (damage in % of total length) (E1)	<10 %	5	35
	11-20 %	4	
	21-30 %	3	
	31-50 %	2	
	>51 %	1	
Sluice gate operation-level of sedimentation with reference to gate opening (SG1)	Below	5	15
	Close to gate	4	
	Same level of gate	3	
	Above gate level	2	

TABLE II PHYSICAL CONDITIONS ASSESSMENT OF CANALS

Parameters	**Class**	**Rank**	**Weightage**
Bank collapse (% of total canal length) (BC)	<10 %	5	30
	11-30 %	4	
	31-50 %	3	
	51-70 %	2	
	>71 %	1	
Water pooling in canal (WP)	<10 %	5	20
	11-20 %	4	
	21-30 %	3	
	31-50 %	2	
	>51 %	1	
Weed growth (WG)	<10 %	5	10
	11-30 %	4	
	31-50 %	3	
	51-70 %	2	
	>71 %	1	
Conveyance loss (CL) (Evaporation +Seepage)	<10 %	5	40
	11-30 %	4	
	31-50 %	3	
	51-70 %	2	
	>71 %	1	

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(CC) = Σ (BC rank x weightage) + (WP rank x weightage) + (WG rank x weightage) + (CL rank x weightage) ……… (2)

The *water infrastructure condition* (WIC) is the product of reservoir storage efficiency and canal conditions. This could be used for prioritizing the infrastructures.

WIC = Σ RSE + CC……………. (3)

Command area developments (CAD) of water infrastructure project are evaluated by the cropped area (CA), and drinking water supply. The cropped area is the product of regulatory constraints (RC) and water sharing issues (WSI). The observed conditions were grouped into class, ranked and assigned weightage (table 3).

CAD = Σ (CA rank x weightage) + (RC rank x weightage) + (WSI rank x weightage) …………. (4)

TABLE III
COMMAND AREA DEVELOPMENT ASSESSMENT

Parameters	Class	Rank	Weightage
Cropped area (referenced to proposed) (CA)	<10 %	5	60
	11-30 %	4	
	31-50 %	3	
	51-70 %	2	
	>71 %	1	
Water flow regulatory constraints (RC)	<10 %	5	20
	11-20 %	4	
	21-30 %	3	
	31-50 %	2	
	>51 %	1	
Water Sharing issues (WSI)	<10 %	5	10
	11-30 %	4	
	31-50 %	3	
	51-70 %	2	
	>71 %	1	

The water infrastructure conditions of the existing systems evaluated on the above said methods is shown in table 4.

VI. RESULTS AND DISCUSSIONS

The goal of river basin development, planning and management is to promote sustainable development and integrate land and water management, by focusing natural resource benefits for regional planning and management strategy. There are six infrastructures having reservoir, canal and command area and others have only storages. Many of the reservoirs are storing below 40% of their capacity except R1, R4, R8, and R6. The canals are operating below it efficiency (<40%), as the impediments for operation (blockage and water loss is high). There is an effective use of water availability in the command area (>40%), as indicated by the cropped area.

TABLE IV
SUSTAINABLE PERFORMANCE OF RESERVOIR AND CANAL AND COMMAND AREAS DEVELOPMENTS- KRISHNA RIVER BASIN

Reservoir ID	Name	Capacity (MCM)	WIC	Score (%)			Total Score (%)	Priority
				RC	CC	CAD		
R1	Kanher Dam	286	46.7	20.1	26.4	10.2	56.7	8
R2	Urmodi Dam	282.14	64	32.0	32.0	17.6	81.6	3
R3	Tarali Dam	165.71	70.9	38.9	32.0	8.2	79.1	4
R4	Dhom Dam	382.32	51.5	27.1	24.4	8.2	59.7	7

R5	Balakwadi Dam	115.53	75.7	38.3	37.4	35.6	111.3	1
R6	Veer Dam	287.5	56.2	34.0	22.2	15.6	71.8	5
R7	Kaas Talav	53.12	79	36.2	42.8	28.8	107.8	2
R8	Ner Talav	36.61	48.2	11.2	37.2	20.4	68.8	6
	Total	1608.93						

The cumulative storage capacity of the infrastructures in the basin is about 1608.93 MCM. Due to the sedimentation, they are able to store only <40% of their capacity. As the rainfall pattern and intensity is changed over the past 8 to 10 years, there is a need to increase the capacity (by removal of sediments and repairing of embankments) of the storage system in meeting the requirements.

TABLE V
REDUCTION IN STORAGE CAPACITY OF RESERVOIRS DUE TO SEDIMENTATION (IN MCM).

Reservoir ID	Name of the Reservoir	Water Spread Area (Km^2)		Max. Height above Foundation (m)	Gross Storage Capacity(MCM)		Sedimentation Level (%)	Reduced Storage Capacity (MCM)
		2012	2013		2012	2013		
R1	Kanher Dam	5.68	3.98	50.34	286.00	200.35	30	85.65
R2	Urmodi Dam	5.63	4.12	50.10	282.14	206.41	27	75.73
R3	Tarali Dam	2.26	1.70	73.41	165.71	124.80	25	40.91
R4	Dhom Dam	7.64	4.58	50.00	382.32	229.24	40	153.08
R5	Balakwadi Dam	1.77	1.42	65.10	115.53	92.44	20	23.09
R6	Veer Dam	8.03	6.10	35.81	287.50	218.44	24	69.06
R7	Kaas Talav	0.55	0.42	14.00	7.75	5.88	24	1.87
R8	Ner Talav	1.23	0.95	12.00	14.76	11.40	23	3.36
				Total	1541.71	1088.96		452.75

VII. CONCLUSIONS

Water storage and distribution systems in semi-arid regions need to be functionally effective in meeting the agriculture and drinking water demand, irrespective of rainfall pattern.

A. Water infrastructure condition (WIC) assessment of a river basin, based on Reservoir Storage Efficiency (RSE), Canal Conditions (CC) and Command Area Development (CAD), assessed and evaluated from Krishna basin can be attempted in other semi-arid regions.
B. WIC could be an effective tool for decision making process, in river basin water resources development planning and management.
C. WIC would portray the water availability scenario under different climate change conditions.
D. There is reduction in gross storage capacity by almost 30% due to sedimentation in the reservoir present in the study area.

VIII. ACKNOWLEDGEMENT

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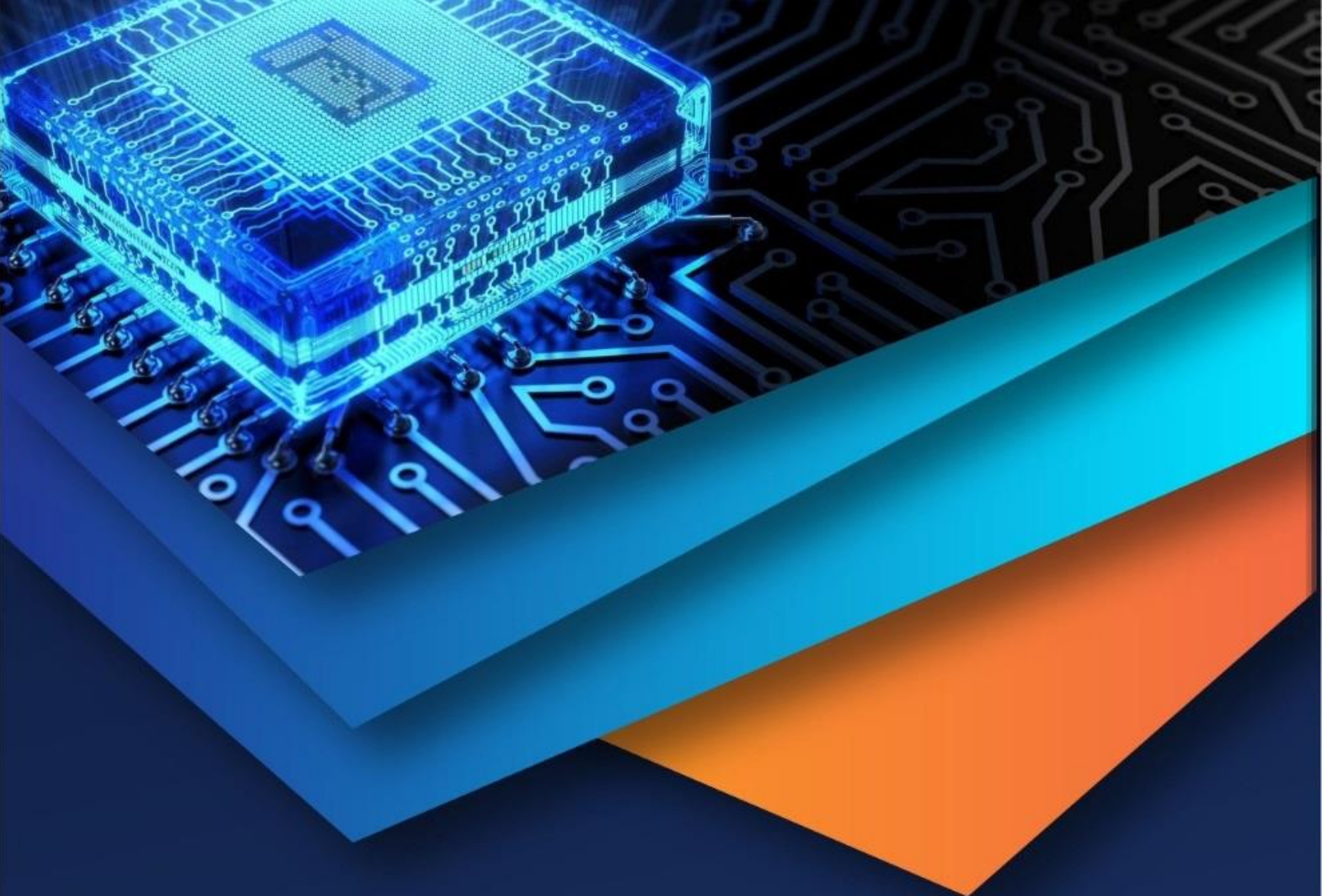

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