

Evaluation of Watershed Development Programme: A Framework for Selection and Aggregation of Key Indicators

ABSTRACT

The measure of the effectiveness of watershed development programmes depends on selecting the right set of evaluation indicators that reflect the programme's goals, including resource management, environmental sustainability, and socio-economic benefits. In this paper, the focus is on the process of selecting and aggregating the key indicators to assess the success of watershed development initiatives. By categorizing indicators into relevant themes such as Terrain Management, Water Resources Utilization, Agronomic Vitality, Livestock Vitality, Employability, Human Empowerment, and Sustainability. This paper highlights the importance of using a structured approach to ensure comprehensive evaluation. Proper selection and aggregation of indicators emphasize the importance of context-specific indicators to ensure accurate and effective programme evaluation and lead to providing valuable insights for programme assessment and future improvements.

Keywords: Watershed, Terrain Management, Agronomic Vitality, Sustainability

INTRODUCTION

Watershed development is a multidisciplinary approach to improve land, water, and vegetation management to achieve agricultural sustainability. Over the past few decades, watershed development programmes have been implemented globally, to address issues such as soil erosion, water scarcity and declining agricultural productivity. These programmes involve integrated resource management approaches that aim to achieve sustainable development.

Evaluating their effectiveness requires a careful selection of key indicators that capture various aspects such as water management, land conservation, and socio-economic benefits. Identifying the right indicators is vital for ensuring that the programme's impacts are adequately assessed, allowing for informed decision-making

and improvement of future interventions (Sharda *et al.*, 2012).

Importance of Selection of Indicators

The selection of indicators is central to the evaluation of watershed development programmes. A well-chosen set of indicators reflects the programme's effectiveness in addressing region-specific issues like soil degradation, water retention, and agricultural sustainability.

Proper indicators are essential for setting up effective monitoring and evaluation of watersheds. Indicators serve as markers to track changes and demonstrate success. These programmes generate a range of benefits, including direct and protective impacts, ecological improvements, and employment generation. The evaluation criteria encompass biophysical, socio-economic, and

sustainability aspects. Key indicators include boosting rainfed agricultural productivity, recharging groundwater for drinking and irrigation, enhancing the productivity of non-arable lands, fostering employment, encouraging collective action and strengthening social institutions (*Atre and Malunjar, 2014*).

Given the complexity and variability of watersheds, there is no universal set of indicators that can be applied across all programmes. Rather, as *Sharda et al., (2012)* argue, the indicators must be adapted to the unique geographical, ecological and socio-economic conditions of each watershed. The importance of bio-physical, socio-economic and sustainability indicators has been emphasized in numerous studies, but the challenge lies in aggregating these indicators into manageable and relevant groups for effective programme evaluation.

Method of Selection of Indicators

The selection process should begin by identifying the key goals of the watershed development programme (*Fenta et al., 2023*). Indicators need to be aligned with these goals to ensure they accurately reflect the programme's outcomes. The selected indicators should be SMART: 'Simple, Measurable, Achievable, Relevant, and Time-sensitive' (*Sharda et al., 2012*) as monitoring every project aspect is impractical.

The selection criteria for indicators typically align with six key categories: (i) their relevance to the specific programme or project; (ii) their appeal or resonance with the target audience; (iii) their ability to respond effectively to changes within the system; (iv) the level of confidence in the data

informing the selection process; (v) the availability of relevant data; and (vi) the practicality of obtaining this data (*Liberati et al., 2020*).

This paper primarily utilizes 28 selected indicators based on the environmental conditions of different watersheds and suggest the aggregation of key evaluation indicators based on Terrain Management, Water Resources Utilization, Agronomic Vitality, Livestock Vitality, Employability, Human Empowerment and Sustainability to build a structured framework for future evaluation.

Aggregation of Indicators

Watershed development programmes encompass a range of components, including: (i) soil and land management; (ii) water management; (iii) crop management; (iv) afforestation; (v) pasture or fodder development; (vi) livestock management; (vii) rural energy management; (viii) additional farm and non-farm activities; and (ix) enhancing community skills and resources. These elements are highly interrelated and interact with one another (*Shilpa et al., 2017; Dutta, 2022*).

Based on these components, the indicators can be organized into thematic categories, including (i) Terrain Management Indices, (ii) Water Resources Utilization Indices, (iii) Agronomic Vitality Indices, (iv) Livestock Vitality Indices, (v) Employability Indices, (vi) Human Empowerment Indices and (vii) Sustainability Indices. This helps in structuring the evaluation and ensuring that all critical areas are covered. By organizing indicators into these categories, evaluators can gain a comprehensive understanding of how

different components of the programme contribute to its overall success.

INDICATORS

1. Terrain Management Indices

“The slope manipulation, different structures and area benefitted from these structures and effect of watershed development works on gullies in watershed have been grouped in the Terrain Management Indices” (Sharda et al., 2012). Details of three indices included in this group are as given below.

1.1.Land Levelling Index (LLI)

To mitigate runoff and soil erosion, particularly from arable land, watershed management programmes often implement land improvement measures aimed at reducing the land's slope. These slope-reduction practices are essential for minimizing soil loss and controlling runoff effectively. “Land Levelling Index (LLI), which is the ratio of recommended land slope to the existing land slope, can be utilized in the pre-project (PrP) and post-project (PoP) scenarios to quantify the extent of land improvement and is defined as:

$$LLI = \frac{\text{Recommended slope (\%)}}{\text{Existing or treated slope (\%)}} \quad \dots (1)$$

Where, Existing slope refers to the individual land slope before the inception of the project and treated slope is the moderated slope resulting from land levelling activities. Higher value of LLI is a measure of better moderation in land slope. LLI can attain a maximum value of 1.0, which refers to a perfectly levelled field”(Sharda et al., 2005; Sharda et al., 2012; Vinchurkar and Ingole, 2021).

1.2.Critical Area Index (CAI)

Before initiating treatment within a watershed, it is essential to identify critical areas to apply targeted bio-engineering measures tailored to specific locations. “For quantifying the total work undertaken at watershed level, Critical Area Index (CAI), which is the ratio of the critical area benefitted due to treatment with conservation structures and the total critical area that needs to be treated is defined as:

$$CAI = \frac{\text{Benefitted critical area from structures}}{\text{Total critical area}} \quad \dots (2)$$

The CAI can attain a maximum value of 1.0 and a higher value of CAI is a measure of better treatment of the critical area”(Sharda et al., 2012; Vinchurkar and Ingole, 2021).

1.3.Gully Stabilization Index (GSI)

This approach is a key indicator for assessing the impact of gully control structures and drainage treatments on stabilizing gullied areas during the post-project (PoP) period.“Gully Stabilization Index (GSI),which is defined as:

$$GSI = \frac{0.5 SR + 0.5 SSR}{SR + SSR} \quad \dots (3)$$

Where, SR is Stream Slope Reduction and SSR is Stream Side Stabilization Ratio, which are defined as:

$$SR = \frac{\text{Equivalent slope of the gullies (\%)}}{\text{Expected equivalent slope (\%)}} \quad \dots (3.1)$$

$$SSR = \frac{\text{Average width of streams after the project}}{\text{Average width of streams before the project}} \quad \dots (3.2)$$

The SSR may be worked out by assigning suitable weights to different streams based on the water volume discharged or stream order (W_i) as:

$$\text{Weighted SSR} = \frac{\sum_{i=1}^n W_i \times SSR_i \text{ after the project}}{\sum_{j=1}^n W_j \times SSR_j \text{ before the project}} \quad \dots (4)$$

Where, n refers to number of streams in the watershed. GSI can have any value between 0 and 100 and a higher value will indicate higher stability of the gullies after the watershed interventions” (Sharda et al., 2012).

2. Water Resources Utilization Indices

In the watershed development programme, we develop water harvesting structures which store some water during the rainy season and definitely by utilizing Such water the productivity can also be increased. In this group such indices have been included and their details are given below.

2.1. Water Storage Capacity Utilization Index

The effectiveness of a watershed management project largely depends on the capacity to harvest water within the watershed and utilize it efficiently. “Water Storage Capacity Utilization Index (WSCUI) combines conservation of water available from all the potential resources within the watershed and its optimal utilization by assigning proper weights to the two aspects and then adding the products. WSCUI is defined as:

$$WSCUI = (0.4SE + 0.6 UE) \times 100 \quad \dots (5)$$

Where, ‘Storage Efficiency (SE), which needs to

be assessed for improving availability and planning of water resources, can be estimated as a ratio of water stored to the designed live storage capacity’, expressed in percent terms:

$$SE = \frac{\sum_{i=1}^n \text{Water actually stored in live storage capacity}}{\sum_{i=1}^n \text{Designed live storage capacity}} \quad \dots (5.1)$$

‘Utilization Efficiency (UE) of the stored water can be computed as a ratio of the total water utilized (i.e. excluding losses through seepage and evapo-transpiration, and unutilized part), and the total water actually stored in live storage.’

$$UE = \frac{\sum_{i=1}^n \text{Total Water utilised out of live storage}}{\sum_{i=1}^n \text{Total Water actually stored in live storage}} \quad \dots (5.2)$$

Where, n = Number of structures.

Storage Efficiency, Utilization Efficiency and Water Storage Capacity Utilization Index can vary from 0 to 100 and a higher value will indicate higher efficiency / utilization” (Sharda et al., 2012).

2.2. Irrigability Index

A primary use of the harvested water is irrigation, which supports sustainable agricultural production across the watershed. “Irrigability Index (II) is a ratio of additional gross irrigated area and net incremental irrigated area. Gross irrigated area may be estimated by adding the net incremental irrigated area as many times as it was irrigated.

$$II = \frac{\text{Additional gross irrigated area}}{\text{Net incremental irrigated area}} \quad \dots (6)$$

The index can attain any value more than 0 and a higher value will indicate successful utilization of harvested water in the watershed management

project”(Sharda *et al.*, 2012; Vinchurkar and Ingole, 2021).

2.3.Conserved Water Productivity Index

“Conserved Water Productivity Index helps in assessing the change in the irrigated crops’ yields in terms of water utilized and is defined as ratio of sum of average equivalent yields per unit of conserved water utilized by crops that were irrigated in terms of targeted production. The value of the index can vary from 0 to 1 and a higher value will indicate achievement closer to the targeted production”(Sharda *et al.*, 2012).

$$CWPI = \frac{\text{Avg. production achieved (equivalent yield)/unit of water}}{\text{Production targeted (equivalent yield)/unit of water}} \quad \dots (7)$$

3. Agronomic Vitality Indices

It is quite obvious that due to development of watershed, there can be increase in cropped area, increase in crop production, change in cropping pattern, change or increase in use of fertilizers, etc in the watershed. All such indices have been grouped under Agronomic Vitality Indices and described below.

3.1.Cultivated Land Utilization Index

The Cultivated Land Utilization Index (CLUI) reflects the influence of watershed interventions on shifts in cultivable land area and crop cultivation duration between pre-project (PrP) and post-project (PoP) periods.“It is calculated by summing the products of land area planted under each crop, multiplied by actual duration of days of that crop and dividing the sum by the total cultivated land area times 365 days as given

below:

$$CLUI = \frac{\sum_{i=1}^n a_i d_i}{A \times 365} \quad \dots (8)$$

Where,

n = Total number of crops,

a_i = Area occupied by i^{th} crop,

d_i = Days that i^{th} crop occupied in the a_i area,

A = Total cultivable land area.

The CLUI can attain a maximum value of 1.0 and higher value of CLUI indicates that the maximum part of cultivable area is under crop production for maximum period in a year”(Sharda *et al.*, 2005; Sharda *et al.*, 2012).

3.2.Crop Productivity Index

Crop productivity improvements at the watershed level are evaluated by the Crop Productivity Index (CPI), which compares average crop productivity to its potential or optimal yield. “It is calculated before and after the project by dividing the crop yield obtained in the watershed by the yield obtained under recommended package of practices or highest yield within the watershed:

$$CPI = \frac{1}{n} \sum_{i=1}^n y_i / Y_i \quad \dots (9)$$

Where,

n = Total number of crops cultivated in the watershed,

y_i = Average yield of i^{th} crop cultivated in the watershed,

Y_i = Yield of i^{th} crop with standard package of practices or highest yield within the watershed.

The CPI can attain any value greater than zero in a

given location. Higher value of CPI is indicative of crops' yields closer to the maximum attainable yield under standard package of practices”(Sharda et al., 2005; Sharda et al., 2012).

3.3.Crop Diversification Index

Crop diversification within watershed projects serves to reduce the risks associated with crop production losses. “Crop Diversification Index (CDI) can be utilized for PrP and PoP scenarios to assess the changes in the cropping patterns due to crop improvement programmes and is defined as follows:

$$CDI = \sum_{i=1}^n P_i \log \frac{1}{P_i} \quad \dots (10)$$

Where,

P_i =Proportion of i^{th} crop in comparison with total cropped area

n = Total number of crops in the watershed.

The CDI can attain any value greater than zero and higher value of CDI is a measure of better crop diversification”(Sharda et al., 2005; Sharda et al., 2012).

3.4.Crop Fertilization Index

To gauge changes in fertilizer usage between PrP and PoP scenarios, a comparison of actual NPK consumption against recommended or required doses provides valuable insights.“The value of Crop Fertilization Index varies from 0 to 1 and a higher value will indicate that the NPK consumption is closer to the recommended or required amount of consumption”(Sharda et al., 2012).

CFI

$$= \frac{\text{Average NPK consumption}}{\text{Recommended/required NPK dose}} \quad \dots (11)$$

3.5.Soil Nutrient Index

“Conservation practices on arable lands, such as minimal tillage, zero tillage, bunding, vegetative barriers, along with mulching, manuring, Integrated Nutrient Management (INM), intercropping, and mixed cropping, help curb nutrient loss from soil erosion and contribute to soil fertility, supporting sustainable yields of crops, vegetables, and fruits. Evaluating changes in soil fertility through nutrient levels across PrP and PoP periods is essential for assessing the impact of watershed management efforts” (Sharda et al., 2012). “Soil Nutrient Index (SNI) is expressed as:

$$SNI = \frac{NI + 2 Nm + 3 Nh}{NI + Nm + Nh} \quad \dots (12)$$

Where,

N is number of samples (depending upon soil type and land use) and l, m and h refer to low, medium and high percentages, respectively of a particular nutrient as per ranges given below:

Organic Carbon (%):

l = low fertility (< 0.5%)

m = medium fertility (0.5% - 0.75%)

h = high fertility (> 0.75%)

Available Nitrogen (N kg/ha):

l = low fertility (< 250 kg/ha)

m = medium fertility (250 - 500 kg/ha)

h = high fertility (> 500 kg/ha)

Available Phosphorus ($P_2 O_5$ kg/ha):

l = low fertility (< 11 kg/ha)

m = medium fertility (11 - 25 kg/ha)

h = high fertility (> 25 kg/ha)

Available Potassium (K₂O kg/ha):

l = low fertility (<120 kg/ha)

m = medium fertility (120-280 kg/ha)

h = high fertility (>280 kg/ha)

“For any of the nutrients, the value of its SNI can attain a value between 1 and 3. A value of 1.0 will indicate that the soil has low fertility whereas a value of 3.0 will indicate that the soil fertility is high in terms of that nutrient. Any value in between the two extreme values will indicate the medium fertility status of the soil”(Sharda *et al.*, 2012).

3.6. Normalized Difference Vegetation Index

This measure is also crucial for identifying improvements in vegetative cover due to bio-engineering initiatives within the watershed. “It can be expressed as:

$$NDVI = \frac{NIR - R}{NIR + R} \times 100 \quad \dots (13)$$

Where,

NIR = Near Infra-Red (0.76 to 0.90 m) radiation,

R = Red (0.63 to 0.69 m) radiation.

The values of NIR and R can be obtained through remotely sensed data. NDVI can have any value varying from 0 to 100 and a higher value indicates better quality of vegetative cover in the PoP scenario as compared to PrP period”(Sharda *et al.*, 2012).

4. Livestock Vitality Indices

As the availability of fodder and grasses

increases in the watershed, a livestock component is added with the agriculture to have stability in income of the inhabitants of the watershed. The indices pertaining to livestock are clubbed under Livestock Vitality indices and are described in following sections.

4.1. Livestock Composition Index

To track changes in livestock composition between pre-project (PrP) and post-project (PoP) scenarios, “the ratio of total livestock units of improved breeds of cows and buffaloes and total livestock units of local breeds of cows and buffaloes is a useful indicator. The ratio can vary from 0 to infinity”(Sharda *et al.*, 2012).

LCI

$$= \frac{\text{Total livestock units of improved buffaloes and crossbred cows}}{\text{Total livestock units of local cows and buffaloes}} \quad \dots (14)$$

4.2. Livestock Production Value Index

“Change in value of production due to changes in livestock composition can be assessed with Livestock Production Value Index (LPVI) which is defined as:

LPVI (at constant price)

$$= \frac{\sum_{i=1}^k \sum_{j=1}^n P_i Y_{ij} X_j / L \text{ after the project}}{\sum_{i=1}^k \sum_{j=1}^n P_i Y_{ij} X_j / L \text{ before the project}} \quad \dots (15)$$

Where,

P_i = Price of ith product (at constant price),

Y_{ij} = Average production of ith product from jth category of animal,

X_j = Number of jth category of animal,

L = Total number of standard livestock units.

A higher value of LPVI indicates increased value

of the livestock production after the implementation of improved animal husbandry practices”(Sharda et al., 2012).

4.3. Carrying Capacity Index

It is essential to examine the watershed's capacity to sustain its livestock population by increasing fodder availability through afforestation and related initiatives. This is a critical aspect of watershed development, aiming to strengthen the livestock sector and its contributions. For this, “the Carrying Capacity Index is a suitable indicator, which is the ratio of the quantity of fodder available and required for the existing livestock population. The value of the index varies from 0 to 1”(Sharda et al., 2012; Vinchurkar and Ingole, 2021).

$$CCI = \frac{\text{Quantity of fodder available}}{(\text{No. of standard livestock units}) \times (\text{Standard requirement of green fodder per livestock unit})} \quad \dots (16)$$

5. Employability Indices

The ultimate aim of the watershed development programme is Socioeconomic development of the inhabitants. With a view to assess this aspect three indices have been included under Employability indices, which will be of help in evaluating the development programme.

5.1. Women Productive Time Utilization Ratio

Women, who make up 32% of the agricultural workforce in the Indian subcontinent, a proportion that is rising due to male outmigration to urban areas, are pivotal in managing natural resources to ensure food and nutritional security. Alongside

daily household responsibilities, women often invest considerable time in resource-gathering tasks, such as fuelwood collection, water gathering, and grazing, particularly in resource-scarce and challenging environments. Watershed management programmes create opportunities for women to channel their labour into more productive roles. “Women Productive Time Utilization Ratio (WPTUR) will help in indirectly assessing the benefits derived by the women stakeholders from watershed management programmes.

WPTUR

$$= \frac{\text{Time spent on more productive activities}}{\text{Time spent on less productive activities}} \quad \dots (17)$$

Where, “more productive activities cover dairying, cottage industry, cropping, horticulture and agri-business while less productive activities include fuel wood collection, water fetching, grazing etc. The ratio can be measured at two points of project period i.e. PrP and PoP. An improvement in the ratio will indicate more productive utilization of the time by women folk in the watershed and vice versa”(Sharda et al., 2012).

5.2. Regular Employment Generation Index

“Watershed Management Programmes generate employment both through land-based activities, such as soil conservation and planting (in horticulture and forestry), and through non-land-based ventures, such as cottage industries or thrift societies for landless rural communities. In case of regular employment, which is more

important than the casual employment, the watershed management impact can be assessed through the Regular Employment Generation Index” (Sharda et al., 2012):

$$\text{REG} = \frac{\sum_i^n E_i A_i (\text{after the project})}{\sum_j^k E_j A_j (\text{before the project})} \quad \dots (18)$$

Where,

E_i = the number of mandays utilized per hectare in the i^{th} enterprise (crop, horticulture, agro-forestry, forestry, livestock, fishery etc.) in a year after the project,

A_i = Area in hectares utilized in the i^{th} enterprise (crop, horticulture, agro-forestry, forestry, livestock, fishery etc.) in a year after the project,

E_j = Number of mandays utilized per hectare in the j^{th} enterprise (crop, horticulture, agro-forestry, forestry, livestock, fishery etc.) in a year before the project,

A_j = Area in hectares utilized in the j^{th} enterprise (crop, horticulture, agro-forestry, forestry, livestock, fishery etc.) in a year before the project,

k, n = Number of enterprises before and after the project, respectively.

Regular Employment Generation Index can attain any positive value and any value higher than 100 will indicate the percentage improvement in regular employment leading to reduction in outmigration” (Sharda et al., 2012; Vinchurkar and Ingole, 2021).

5.3. Seasonal Outmigration Ratio

By enhancing irrigation, cropping intensity, and crop diversification, watershed management

can significantly reduce outmigration. With increased productivity in the watershed, seasonal migrants often find viable employment locally, fostering economic stability within the region. “The impact of a watershed management project on the socio-economic malady of outmigration can be assessed through the Seasonal Outmigration Ratio (SOR), which is defined as:

$$\text{SOR} = \frac{\sum_i^n D_i (\text{after the project})}{\sum_j^n D_j (\text{before the project})} \quad \dots (19)$$

Where,

D_i = is the number of days out migrated by i^{th} out-migrant in a year after the project,

D_j = is the number of days out migrated by j^{th} out-migrant in a year before the project.

“Seasonal Outmigration Ratio can attain any value and zero value will indicate that outmigration has been completely eliminated, while unit value will indicate no change in outmigration” (Sharda et al., 2012).

6. Human Empowerment Indices

“The empowerment of people living in the watershed needs to be done. The assessment needs certain indices which are clubbed under Human Empowerment indices. One important index, i.e. Human development index (HDI) is as defined by United Nations Development Program (UNDP). All these indices are described in following sections” (Sharda et al., 2012).

6.1. Poverty Index

“It is simply percentage of families below poverty line (BPL) based on their real annual income within the watershed:

$$PI = \frac{\text{Number of BPL families}}{\text{Total Number of families}} \times 100 \quad \dots (20)$$

Poverty Index can have a value ranging from 0 to 100 and it can be utilized in PrP and PoP scenarios to assess the change in number of poor stakeholder families within the watershed”(Sharda et al., 2012; Vinchurkar and Ingole, 2021).

6.2.Social Equity Index

Social equity is a fundamental criterion for evaluating the success of watershed management programmes. “Social Equity Index (SEI) combines equity in income distribution, budget sharing, contributions made and benefit sharing by assigning proper weights to the four aspects and then adding the products:

$$SEI = \frac{3 \text{ IGR} + 2 \text{ BuSGR} + 2 \text{ CGR} + 3 \text{ BeSGR}}{10} \times 100 \quad \dots (21)$$

Where,

Income Gini Ratio (IGR)

$$= 1 - \sum_{i=1}^n P_i (q_i + q_{i-1}) \quad \dots (21.1)$$

Budget Sharing Gini Ratio (BuSGR)

$$= 1 - \sum_{i=1}^n P_i (b_i + b_{i-1}) \quad \dots (21.2)$$

Contribution Gini Ratio (CGR)

$$= 1 - \sum_{i=1}^n P_i (c_i + c_{i-1}) \quad \dots (21.3)$$

Benefit Sharing Gini Ratio (BeSGR)

$$= 1 - \sum_{i=1}^n P_i (d_i + d_{i-1}) \quad \dots (21.4)$$

Where,

P_i = Proportion of population in i^{th} class,

q_i = Cumulative proportion of income upto i^{th} class,

b_i = Cumulative proportion of budget shared upto i^{th} class,

c_i = Cumulative proportion of contributions made upto i^{th} class,

d_i = Cumulative proportion of benefits shared upto i^{th} class.

Social Equity Index can vary from 0 to 100 and a lower value will indicate higher social equity”(Sharda et al., 2012).

6.3.Enterprise Cost Effectiveness Index

The benefits gained from introducing improved technology in a watershed can serve as a, “Enterprise Cost Effectiveness Index which can be defined as:

ECEI

$$= \frac{\frac{\text{Benefits from improved technology (Rs./ha)}}{\text{Benefits from traditional practice (Rs./ha)}}}{\frac{\text{Cost of production through improved technology (Rs./ha)}}{\text{Cost of production through existing technology (Rs./ha)}}} \times 100 \quad \dots (22)$$

It can be computed separately for different physiographic locations of the watershed and for each important technology. The value of ECEI may vary from 0 to 100 and a higher value indicates higher net returns from the improved technology as compared to traditional practice followed by the farmers during the PrP period”(Sharda et al., 2012).

6.4.Human Development Index (Anonymous, 2008)

“The HDI is a summary measure of human development. It measures the average achievements in a country in three basic dimensions of human development:

- A long and healthy life, as measured by life expectancy at birth.
- Knowledge, as measured by the adult literacy rate (with two-thirds weight) and the combined primary, secondary and tertiary gross enrolment ratio (with one-third weight).
- A decent standard of living, as measured by (Gross Domestic Production) GDP per capita in purchasing power parity (PPP) terms in US dollars.

Though HDI is usually computed for a country, here it is considered for computation in a watershed as it provides a comprehensive result of human empowerment. Before the HDI itself is calculated, an index needs to be created for each of these dimensions. To calculate these indices-the life expectancy, education and GDP indices-minimum and maximum values (goalposts) are chosen for each underlying indicator. Performance in each dimension is expressed as a value between 0 and 1 by applying the following general formula:

$$\text{Dimension Index} = \frac{\text{Actual value} - \text{Minimum value}}{\text{Maximum value} - \text{Minimum value}} \quad \dots (23)$$

Table 1. Goalposts for calculating the HDI

Indicator	Maximum Value	Minimum Value
Life expectancy at birth (years)	85	25
Adult literacy rate (%)	100	0
Combined gross enrolment ratio (%)	100	0

GDP per capita (PPP US\$)	40,000	100
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Once the dimension indices have been calculated, determining the HDI is straightforward. It is a simple average of the three-dimension indices” (*Kharat and Pawar, 2012*).

$$\text{HDI} = 1/3 (\text{life expectancy index}) + 1/3 (\text{education index}) + 1/3 (\text{GDP index}) \quad \dots (24)$$

Where,

$$\text{Education Index} = 2/3 (\text{Adult literacy index}) + 1/3 (\text{Gross enrolment ratio}) \quad \dots (24.1)$$

GDP Index

$$\begin{aligned} & \text{Log (Actual GDP per capita in USD)} - \text{Log (US \$100)} \quad \dots (24.2) \\ & = \frac{\text{Log (US \$40000)} - \text{Log (US \$ 100)}}{\text{Log (US \$40000)} - \text{Log (US \$ 100)}} \end{aligned}$$

7. Sustainability Indicators

To ensure the long-term viability of watershed development efforts, it is essential to evaluate their overall impact with a focus on sustainability. Key indicators for sustainability assessment are outlined in the following section:

7.1.Runoff Conservation Index

One critical measure is the extent of runoff conserved within the watershed, supporting biomass production and groundwater recharge following targeted interventions. “It can be expressed as:

RCI

$$\text{RCI} = \frac{\text{Runoff water conserved in the watershed after the project}}{\text{Runoff water estimated before the project}} \times 100 \quad \dots (25)$$

The runoff water conserved in the watershed can be computed by estimating the runoff by

hydrologic soil cover complex number method after the implementation of agronomical, vegetative and engineering measures, which affect the land use and topographical characteristics of the watershed and subtracting it from the estimated runoff during the pre-project period.

The value of RCI may vary from 0 to 100 and a value of 100 denotes that the entire runoff from the watershed in the PrP period has been intercepted and conserved within the watershed in the PoP scenario. It may, however, not be desirable from environmental flow point of view”(Sharda *et al.*, 2012; Vinchurkar and Ingole, 2021).

7.2. Soil Erosion Risk Index

A primary objective of watershed development programmes is to reduce soil erosion within the watershed. The effectiveness of these efforts is measured by evaluating soil loss against acceptable thresholds. “Soil Erosion Risk Index (SERI) indicates the change brought about in the soil loss occurring in a watershed in terms of ratio of total permissible soil loss as per soil loss tolerance limit of different homogenous units (in terms of soil depth, infiltration rate, bulk density, erodibility factor, organic carbon and fertility status) of a watershed and the total actual prevailing soil loss occurring from these units of the watershed.

SERI

$$= \frac{\sum_{i=1}^n \frac{\text{Permissible soil loss } \left(\frac{t}{ha}\right) \text{ as per Soil Loss Tolerance Limit in the } i\text{th homogenous unit of watershed}}{\sum_{i=1}^n \frac{\text{Prevailing soil loss } \left(\frac{t}{ha}\right) \text{ in the } i\text{th homogenous unit of watershed}}}{\dots} \quad (26)$$

Where,

i is a homogenous unit of the watershed in terms of soil depth, infiltration rate, bulk density, erodibility factor, organic carbon and fertility status.

The value of the index can vary from 0 to 1 and in some cases even higher. Higher value of SERI is a measure of better moderation in soil loss, whereas a very low value near to zero indicates that the watershed is suffering from a soil loss significantly more than its permissible limit and is at risk of degrading”(Sharda *et al.*, 2012).

7.3. Drought Resilience Ratio

Drought tolerance within a watershed can be evaluated by comparing the weighted equivalent yields of food, fodder, and horticultural crops during drought and normal years. “Drought Resilience Ratio can be estimated for rainfed, irrigated and watershed as a whole for the adopted watershed and non-adopted area outside the watershed. The value of the indicator can vary from 0 to 1 and a higher value will indicate higher resilience to drought”(Sharda *et al.*, 2012).

DRR

$$= \frac{0.5(\text{equivalent food crop production}) + 0.3(\text{equivalent fodder production}) + 0.2(\text{equivalent horti crops production}) \text{ in a drought year}}{0.5(\text{equivalent food crop production}) + 0.3(\text{equivalent fodder production}) + 0.2(\text{equivalent horti crops production}) \text{ in a normal year}} \quad \dots(27)$$

7.4. Induced Watershed Eco-Index

The Induced Watershed Eco-Index (IWEI) tracks the increase in vegetative cover—through crops, pastures, grasslands, and horticultural and forestry plantations—over the project period. “IWEI is calculated as the additional area made green through watershed interventions in proportion to the total watershed area as given below:

$$\text{IWEI} = \frac{\text{Additional area vegetated during the project}}{\text{Total area of the watershed}} \quad \dots (28)$$

The IWEI can attain a maximum value of 1.0, which indicates that whole of the watershed area has been brought under some form of vegetation”(Sharda et al., 2005; Sharda et al., 2012; Vinchurkar and Ingole, 2021).

7.5. Participatory Watershed Development Index (PWDI)

Participation Paradigm Index and Participatory Watershed Development Index (Dogra et al., 2005) have been developed to quantitatively assess stakeholder involvement in these programmes. “It is expressed as,

$$\text{PWDI} = \frac{\sum_{i=1}^{10} \text{Weighted score}}{\sum_{i=1}^{10} \text{Maximum weighted score}} \times 100 \quad \dots (29)$$

Where,

$i=i^{\text{th}}$ major component of participatory watershed development (Participation, Transparency, Watershed Plan Preparation, Watershed Stakeholders Institutions, Watershed Meetings, Accounts and Records, Monitoring and Withdrawal Strategy, Common Property Resource Management, Project Implementing Agency, Watershed Development Team and Equity). For each of the individual component:

$$\text{PPdI} = \frac{\text{weighted score}}{\text{Maximum weighted score}} \times 100 \quad \dots (30)$$

Participatory Watershed Development Index and Participation Paradigm Index can have values ranging from 0 to 100 and a higher value will indicate that higher numbers of the participatory aspects of the programmes have been executed”(Sharda et al., 2005; Sharda et al., 2012; Vinchurkar and Ingole, 2021).

7.6. Benefit Cost Ratio

Economic evaluation is conducted separately for arable and non-arable land and for the watershed as a whole, using the Benefit-Cost Ratio (BCR) to measure project value and feasibility. “It is defined as the ratio of present value of additional gross benefits to the present value of additional total costs as given below:

Benefit Cost Ratio (BCR)

$$= \sum_{t=1}^n \frac{B_t / (1+i)^t}{C_t / (1+i)^t} \quad \dots (31)$$

Where,

B_t are the additional benefits (Rs.) at time t

C_t are the additional costs (Rs.) at time t

i is discount rate (%); and t is life of the project.

Benefit Cost Ratio can attain any value equal to or more than zero. Projects with $BCR > 1.0$ are considered as economically viable and economic soundness of the project increases as the BCR value increases”(Sharda *et al.*, 2005; Sharda *et al.*, 2012).

CONCLUSION

The selection and aggregation of key indicators are essential steps in the evaluation of watershed development programmes. Indicators must be carefully chosen to reflect the programme’s goals, ensuring that its effectiveness can be accurately measured across multiple dimensions such as water management, land conservation and socio-economic development. By selecting relevant and measurable indicators, evaluators can provide valuable insights into the programme’s performance and guide future improvements. This process is crucial for promoting sustainable development and ensuring that watershed initiatives achieve their intended outcomes through corrective steps in the future, if necessary.

FUTURE RESEARCH DIRECTIONS

Future research is needed to prioritize these indicators for diverse watershed contexts and arrive at more meaningful and holistic evaluation of the watershed development programme.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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