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Climate change impact on design and costing of soil and water conservation structures in watersheds

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A study was carried out to determine the effect of climate change on design rainfall and its effect on design and costing of soil and water conservation structures in watersheds. For this study, the micro watershed located at Central Soil and Water Conservation Research and Training Institute, Research Centre, Research farm, Vasad was selected and rainfall data from 1957 to 2012 was used. The analysis showed that as a result of climate change, there is significant increase in number of extremely heavy rainfall days as well as rainfall amount. The design rainfall of various soil and water conservation structures has increased by 11%, 30% and 38% for design of staggered contour trenches, contour bunds and check dams respectively. The cost of construction of staggered contour trenches, contour bunds and check dams in watersheds has increased by 26%, 28% and 12% respectively. This study reveals that, there is a need to account for design and costing of soil and water conservation structures in the light of the climate change and a relook into the watershed programmes of the central Gujarat region of India.

Keywords: Climate change, design and costing, soil and water conservation structures, watersheds.

THE rainfall received in an area is an important factor in determining the amount of water available to meet various demands, such as agricultural, industrial, domestic supply and hydroelectric power generation. The global climatic data analysis clearly confirms a change in the climate[1]. In India, too, the effect of climate change on rainfall, rainy days and water resources has been studied, which bears testimony to changes in these parameters over a long-term basis[2–5]. Global climate changes may also influence long-term rainfall patterns impacting the availability of water, along with the increasing occurrences of droughts and floods. Studies[2,6–10] show that, in general, the frequency of more intense rainfall events in many parts of Asia has increased, whereas the number of rainy days and total annual precipitation have decreased. Due to climate change impact, the irrigated maize, wheat and mustard in the northeastern (NE) and coastal regions, and rice, sorghum and maize in the Western Ghats (WG), may lose[11]. Impacts of climate change and climate variability on the water resources affect the stream hydrology. Stream flows may rise drastically in the monsoon season, but will decrease in the non-monsoon season due to the projected future climate change[12,13].

The watershed management programme (WMP) is aimed at managing the precipitation (rainfall) in such a manner that it reduces runoff controls flood and helps in water harvesting (surface or subsurface) so as to be used during lean period for successfully raising the crops, and for other uses such as aquaculture or livestock, or both. It also maintains soil fertility, and does not accelerate soil loss. The watershed management programme provides livelihood support to the farmers as well. The watershed-based rural development management programmes are

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designed for retention and detention of excess rainfall through engineering measures, namely bunding, trenching, terracing, water-harvesting structures and gully plugging. Biological measures like contour cultivation; mulching; deep tillage; no or zero tillage; mixed, relay, alley and inter cropping; use of organic manure; agro-forestry; agri-horticulture, silvi-pasture; horti-pasture; social forestry and planting of suitable vegetation also help in conserving the runoff and retaining soil loss. All these activities help in flood prevention, drought mitigation and carbon sequestration, which are relevant issues under mitigation options needed in a climate change scenario[13]. Watershed management is the rational utilization of land and water resources for optimum production with minimum hazard to natural resources. It essentially relates to soil and water conservation in the watershed, which means proper land use, protecting land against all forms of deterioration, building and maintaining soil fertility, proper management of local water for drainage, flood protection and sediment reduction and increasing productivity from all land uses. In India, the watershed management programmes implemented by various organizations, departments have revealed the positive results related to natural resources namely water, soil and vegetation[14–18]. In India, under watershed management programmes, mainly bunding in arable lands, trenching in non-arable lands and check dams in drainage lines have been implemented. The design and estimation of these structures were based on the design rainfall and watershed characteristics of the corresponding locations. The impact of climate change on 24-h design rainfall in different locations of China has been reported[19]. The hydrological consequences of extreme rainfall in a changing climate have a major impact on the design of hydraulic works in a watershed[20]. The occurrence of extreme rainfall events may also influence the design rainfall of the corresponding location. These changes in design rainfall may also affect the changes in design and costing of soil and water conservation structures in watersheds. Keeping these considerations in view, there is need to study the effect of climate change on design rainfall and its effect on design and costing of soil and water conservation structures in watersheds.

For the present study, the micro watershed located at Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Research Centre (RC), Research farm, Vasad and surrounding farmers' fields were selected. The research farm has a meteorological observatory, where the weather data are being recorded since 1957. The rainfall data recorded from 1957 till date was used. The micro watershed is located at 73.0806°E, 22.4574°N in Mahi basin, Anand district of Central Gujarat, which is 18 km from Anand town and 22 km from Vadodara city. The watershed has arable and non-arable lands and drainage lines (Figure 1). The soils of the watershed are sandy loam with infiltration capacity of 3–5 cm/h, field capacity 19–20% and wilting point 7–8.5%. Soil pH ranges from 7.5 to 7.84 and electrical conductivity is 0.16 dSm^{-1}. Soils are poor in fertility with organic carbon ranging from 0.30% to 0.35%. Average (last 50 years) annual rainfall of experimental site is 871 mm with 94% concentrated in the period June–September. July and August combined receives 61% of annual rainfall. Annual pan evaporation is 2119.4 mm which shows large deficit of moisture for long periods, and favourable crop growing conditions is restricted to 114 days. Average annual maximum and minimum temperatures are 33.7°C and 18.9°C respectively. In this micro watershed, field bunding in cultivated lands, contour trenching in non-arable lands, i.e. forest lands and check dams in drainage lines have been proposed.

The rainfall data from 1957 to 2012 of the meteorological observatory located at CSWCRTI, RC, was analysed. The year-wise rainfall amount, number of rainy days, frequency of heavy rainfall days (including very

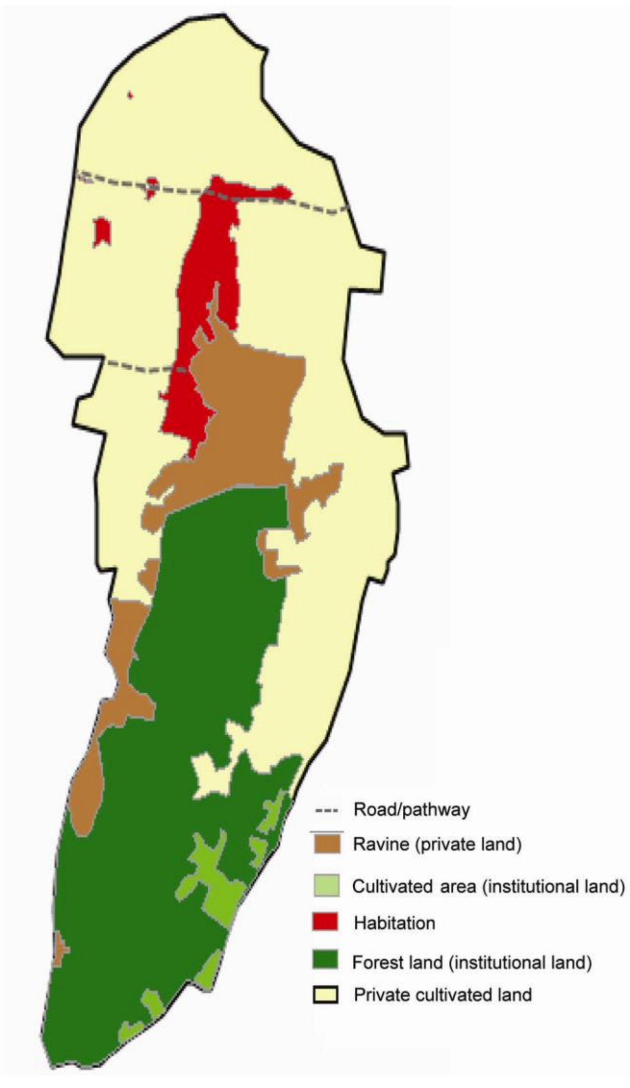

Figure 1. Selected watershed.

heavy and extremely heavy) were determined. A day is called 'heavy rainfall day' if rainfall during that day is 64.5 mm or more according to India Meteorological Department (IMD). This includes very heavy (i.e. 124.5–244.5 mm) and extremely heavy (i.e. >244.5 mm) rainfall. The annual and decadal data analysis was performed.

The adequacy of length of record was determined by the method proposed by Mockus[21]. The length of record for this watershed was found to be 16 years. However, 30 years of data were used for calculating the one-day maximum rainfall of different return periods. For most of the soil and water conservation structures, one-day maximum rainfall in different return periods was used. The one-day maximum rainfall of 30 year period was plotted using Weibull's plotting position method. These plotted data were fitted by Gumbel probability distribution[22] and from that one-day maximum rainfall of 1, 2, 5, 10, 25, 50 and 100 years return period in different decades was done (Figure 2).

In watershed programmes contour bunds are more extensively implemented in arable lands up to 10% slope. Bunding is practised to intercept the runoff flowing down the slope by an embankment with either open or closed ends to conserve moisture, as well as reduce soil and nutrients losses and thereby increase the crop yields in rainfed areas. The cross-section of the bunds will depend on rainfall factor, soil characteristics and slope of the land. The cross-section represents the top width, bottom width, height and slope (Figure 3). Among these, top width is usually kept as 0.3 or 0.45 m and side slope 1 : 1, while height is variable. Height is the major factor which controls the cross-section. Height of the bund is normally calculated based on one-day maximum rainfall in 10 years return period. The following formula was used to calculate the cross-section of the bund.

$$\text{Cross-sectional area} = (\text{bottom width} + \text{top width})/2 * \text{height}, \quad (1)$$

$$h = \sqrt{\frac{\mathrm{Re} \times \mathrm{VI}}{50}}, \quad (2)$$

where h is the height of the bund (m), Re the rainfall excess (cm) and VI is the vertical interval (m).

The rainfall excess, i.e. runoff was estimated by NRCS curve number method[23], in which the interrelationship between initial abstraction (I_a) and potential maximum retention (S) (a) $I_a = 0.1S$ for black soil regions with AMC-I and AMC-II, (b) $I_a = 0.3S$ for all other regions, as proposed for the Indian watersheds[24] was used. The curve numbers were selected from a handbook[24] based on the watershed and rainfall characteristics. Potential maximum retention was estimated from these curve numbers using eq. (5). Runoff was estimated from the potential maximum retention and one-day maximum rainfall of 10 years return period using eq. (4)

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}, \quad (3)$$

where P is the storm rainfall (mm) and Q the direct runoff (mm)

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)} \text{ for } I_a = 0.3S, \quad (4)$$

$$\text{Curve number CN} = \frac{25,400}{(254 + S)}. \quad (5)$$

The runoff, height of the bund, cross-sectional area, earthwork/ha and cost/ha in cultivated lands of the watershed (Figure 1) were estimated for different decades. For cost calculation, the prevailing earthwork rate at CSWCRTI, RC, Research Farm, Vasad for bunding, i.e. Rs 90/cum was used uniformly for all the decades.

Trenching is one of the most efficient technologies for restoration of degraded lands which brings desirable changes though *in situ* conservation of moisture, soil, nutrients and energy fluxes. A contour trench is a micro depression or tiny reservoir constructed across the slope without a spillway with the objective to harvest runoff, eroded soil, nutrient, organic matter, etc. and provides an opportunity to the collected runoff either to get infiltrated or evaporate before the occurrence of the next rainfall. Contour trenching is an effective storm management

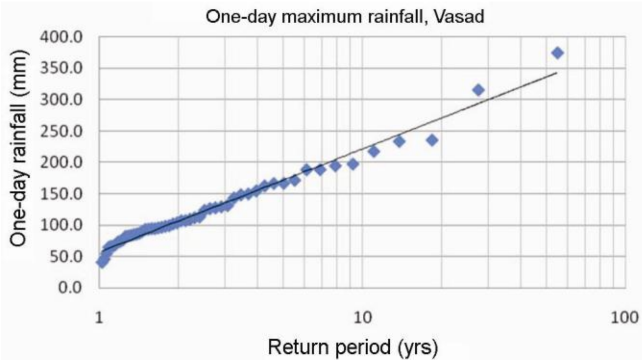

Figure 2. One-day maximum rainfall of 30-yr period plotted using Weibull's plotting position.

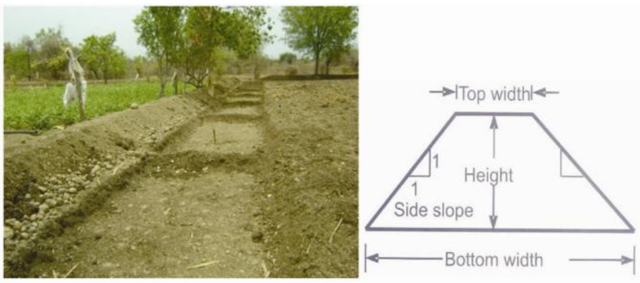

Figure 3. Contour bund specifications.

option for the control of runoff-related fluxes from micro catchments or small watersheds. The design of trenching is based on one-day maximum rainfall of 2 years return period. Using one-day maximum rainfall of 2 years return period, runoff was estimated by the NRCS curve number method, as explained. From the estimated runoff, the number of trenches was determined with 60% and 100% runoff harvesting. The trench size considered was 0.5 m × 0.5 m × 2 m (width × depth × length) as reported by earlier studies[25]. The earthwork/ha and cost/ha were estimated for different decades with 60% and 100% runoff harvesting. For cost calculation, the earthwork rate prevailing at CSWCRTI, RC, Research Farm, Vasad for staggered contour trenches, i.e. Rs 100/cum was used uniformly for all decades. The valuation done at constant price avoids price variability over the years. This attributes the changes in costs to earthwork variability due to climate change alone and not price variability.

Check dams have been constructed in watershed programmes to store runoff water and thereby increase the availability of surface and groundwater resources (Figure 4). Check dam has been synonymous of the watershed programme. Depending upon size of the nala, its slope, watershed area and severity of the problem, suitable type of check dam can be selected. Various parts of the check dam are shown. The spillway is a weir structure. Flow passes through the weir opening, drops to an approximately level apron and then passes into the downstream channel. Three steps in design of the check dam are hydrologic design, hydraulic design and structural design. In hydrologic design, peak rate of runoff and runoff volume are estimated at the site of construction for a particular return period depending upon type of structure. Peak rate of runoff can be estimated using the rational formula.

Peak discharge is generally computed using the rational formula as follows

$$Q = \frac{CIA}{360}, \tag{6}$$

where Q is the peak discharge (cumec), C the runoff factor or coefficient, I the rainfall intensity for a duration equal to time of concentration for a particular return period (mm/h) and A is the watershed area (ha).

In hydraulic design, determination of height of the structure and spillway dimension is important. Standard formula of hydraulic flow is then used to compute dimensions of various components of the structure. The following formula gives the relationship between peak discharge and length and depth of the weir

$$Q = 1.711Lh^{3/2}/(1.1 + 0.01F), \tag{7}$$

where Q is the peak discharge (cumec), L the length of the weir (m), h the total depth of the weir, including freeboard (m) and F is the fall (m).

Figure 4. Check dam in the drainage line.

The earthwork, concrete, brick-work quantities and total cost of the proposed check dam in the drainage line were estimated with increase in design rainfall intensity by 20%, 30% and 40% of existing design rainfall intensities in 1980s. For cost calculation, the prevailing rates at CSWCRTI, RC, Research Farm, Vasad were used uniformly for all the intensities.

The decade-wise average annual rainfall amount and number of rainy days are shown in the Figure 5 *a* and *b* respectively. From the figures, it can be observed that there is an increasing trend of annual rainfall, but there is not much change in average number of rainy days. The decade-wise frequency of heavy rainfall days and one-day maximum rainfall amount are shown in the Figure 5 *c* and *d* respectively. From these figures, it can be observed that there is an increase in number of extremely heavy rainfall days as well as rainfall amount. The increase in one-day maximum rainfall can also affect the design rainfall of the various soil and water conservation structures.

The decade-wise one-day maximum rainfall for different return periods is given in Figure 6. From figure, it can be observed that decadal one-day maximum rainfall increases with time. For the design of contour trenches, one-day maximum rainfall of 2 years return period is mostly used. From Table 1, it can be inferred that the design rainfall of contour trenches has increased by 11%. For design of contour bunds, one-day maximum rainfall of 10 years return period is mostly used. This was also reported by other studies[13,26]. From Table 2 it can be inferred that the design rainfall for contour bunds has increased by 30%. The increase in design rainfall of various soil and water conservation structures is due to the occurrence of extreme rainfall events in recent years, as explained above. This analysis confirms that in recent years, there is increase in design rainfall of the soil and water conservation structures due to climate change. It also indicates that there is a necessity to relook the design rainfall of various soil and water conservation structures in different parts of India.

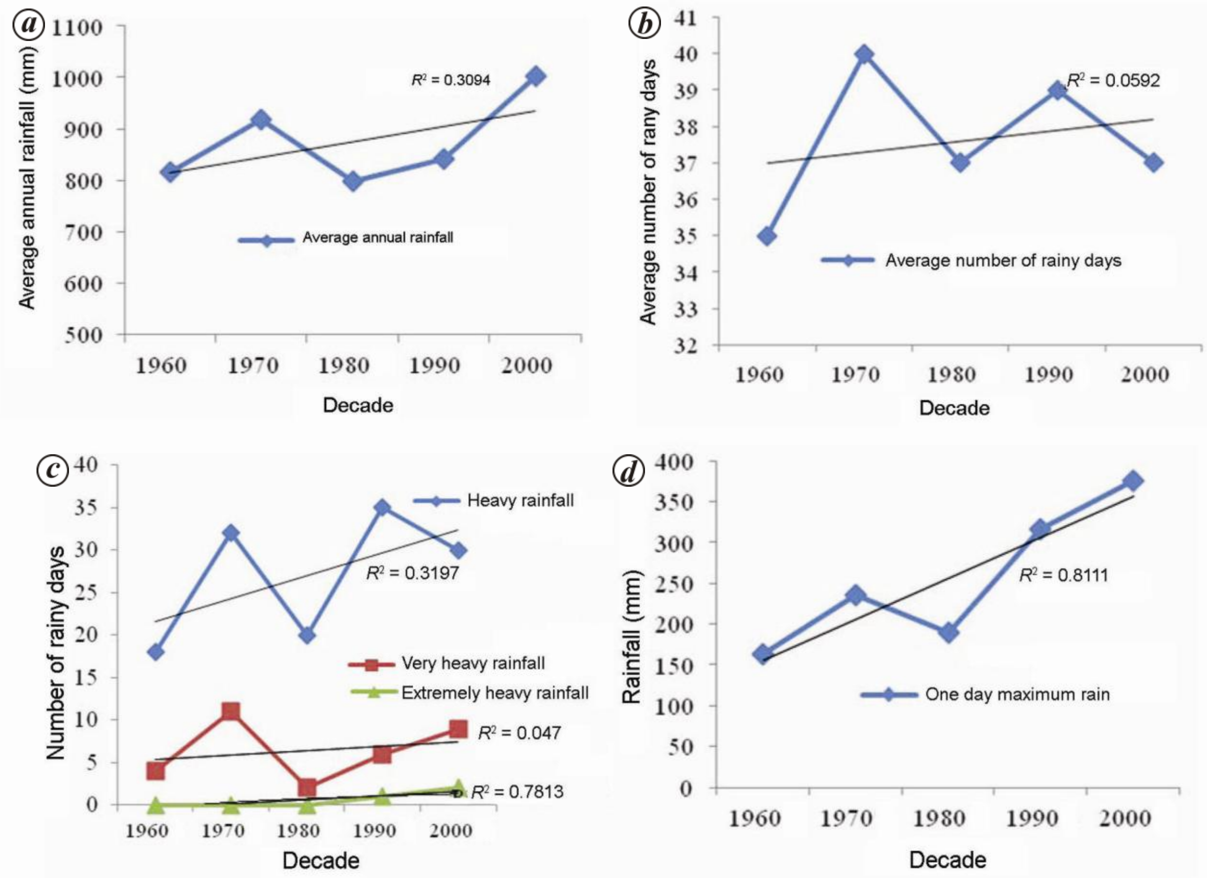

Figure 5. Various rainfall parameters in decade wise. ***a***, Average annual rainfall; ***b***, Frequency of average number of rainy days; ***c***, Frequency of heavy rainfall days; ***d***, One-day maximum rainfall amount.

Table 1. Effect of climate change on design and costing of staggered contour trenches with 60% runoff harvesting

Decade	Design rainfall (mm)	Runoff (mm)	Number of trenches/ha	Earthwork (m^3/ha)	Cost (Rs/ha)
1980s	112	29.63	356	178	17,800
1990s	121	35.42	425	213	21,300
2000s	124 (11)	37.41	449 (26)	224 (26)	22,400 (26)

Values in parenthesis represent percentage increase over 1980s.

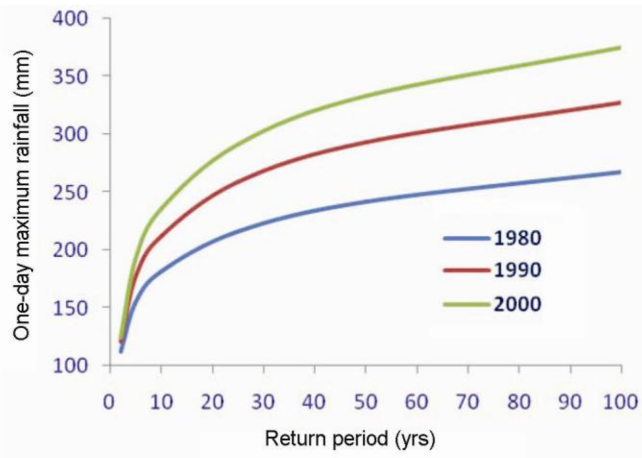

Figure 6. Decade-wise one-day maximum rainfall for different return periods.

Effect of climate change on design and costing of various soil and water conservation structures such as contour bunding, contour trenches and check dams is presented below.

The decade-wise design and costing of contour bunds is presented in Table 2. Due to decade-wise increase in one-day maximum rainfall, the volume of runoff has increased from 119.49 to 171.33 mm, height from 0.54 to 0.63 m, cross-section from 0.45 to 0.58 m^2, earthwork from 112 to 143 m^3 and cost from Rs 10,080 to Rs 12,870/ha. The increase in design rainfall due to extreme rainfall events has increased the contour bund height by 16%, and earthwork quantities and cost by 28%. Tripathi and Sharda[13] also reported the increase in one-day maximum rainfall by 20%, 40% and 60% and the corresponding increase in cross-section by 30.9%, 65.5% and

Table 2. Effect of climate change on design and costing of contour bunds

Decade	Design rainfall (mm)	Runoff (mm)	Bund height (m)	Cross-section (m^2)	Earthwork (m^3/ha)	Cost (Rs/ha)
1980s	181	119.49	0.54	0.45	112	10,080
1990s	213	149.48	0.59	0.53	130	11,700
2000s	236	171.33	0.63 (16%)	0.58	143 (28)	12,870 (28)

Values in parenthesis represent percentage increase over 1980s.

Table 3. Effect of climate change on design and costing staggered contour trenches with 100% runoff harvesting

Decade	Design rainfall (mm)	Runoff (mm)	Number of trenches/ha	Earthwork (m^3/ha)	Cost (Rs/ha)
1980s	112	29.63	593	296	29,600
1990s	121	35.42	708	354	35,400
2000s	124 (11)	37.41	748 (26)	374 (26)	37,400 (26)

Values in parenthesis represent percentage increase over 1980s.

Table 4. Effect of climate change on design and costing of brick masonry check dam

Design rainfall intensity (mm/h)	Peak runoff (m^3/sec)	Earthwork (m^3)	Concrete work (m^3)	Brick work (m^3)	Cost (Rs/check dam)
100	7.5	13.5	5.2	38	184,279
120	9	14.5	5.6	40	193,921
130	9.75	15	5.9	41	199,720
140	10.5	16 (19)	6.2 (19)	42 (11)	205,505 (12)

Values in parenthesis represent percentage increase over 1980s.

103.6%. This implies that there is need to relook the design and costing of contour bunds in different parts of India with changing climatic scenario.

The decade-wise design and costing of staggered contour trenches with 60% and 100% runoff harvesting are presented in Tables 1 and 3 respectively. Due to decade wise increase in one-day maximum rainfall, the volume of runoff has increased from 29.63 to 37.41 mm, number of trenches from 356 to 449/ha, earthwork from 178 to 224 m^3/ha and cost from Rs 17,800 to 22,400/ha for 60% runoff harvesting. Similarly, in case of 100% water harvesting, the number of trenches has increased from 593 to 748/ha, earthwork from 296 to 374 m^3/ha and cost from Rs 29,600 to 37,400/ha. The extreme rainfall events in the recent past have increased the trench design quantities and cost by 26%.

The decade-wise design and costing of brick masonry check dam in drainage line of the watershed is presented in Table 4. Due to increase in designed rainfall intensity, the peak runoff has increased from 7.5–10.5 m^3/sec, earthwork quantities from 13.5 to 16 m^3, concrete quantities from 5.2 to 6.2 m^3, brick masonry from 38 to 42 m^3 and cost from Rs 184,279 to Rs 205,505/check dam. The extreme rainfall events in the recent past have increased the peak runoff rate by 40% and cost by 12%.

The present analysis showed that as a result of climate change, there is significant increase in the number of extremely heavy rainfall days (as defined by IMD) as well as rainfall amount. This increase in one-day maxim rainfall affects the design rainfall of various soil and water conservation structures. The increase in design rainfall of various soil and water conservation structures is due to occurrence of extreme rainfall events in recent years which has increased by 11%, 30% and 38% for design of staggered contour trenches, contour bunds and check dams respectively. The cost of construction of staggered contour trenches, contour bunds and check dams in watersheds has increased by 26%, 28% and 12% respectively. The Department of Land Resources under the Ministry of Rural Development, Government of India has prescribed enhanced cost norms from Rs 6,000 to Rs 12,000/ha in plain areas and Rs 15,000/ha in difficult areas as a common guideline in the execution of the watershed management programmes in the country[27]. Normally, the rise in cost is accounted by the price rises in the economy and compensates for the losses incurred due to enhanced spending on various measures. There is a need to account for design change in soil and water conservation structures caused by climate change, which could enhance the design cost by up to 28%. The conventional design and costing prescribed for common soil and water conservation structures in watersheds, in the light of climate change, might need a relook regarding all the programmes of the Government of India, more so, in areas highly vulnerable to climate change impact.

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Sea-level-rise trends off the Indian coasts during the last two decades

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The present communication discusses sea-level-rise trends in the north Indian Ocean, particularly off the Indian coasts, based on estimates derived from satellite altimeter and tide-gauge data. Altimeter data analysis over the 1993–2012 period reveals that the rate of sea-level rise is rather spatially homogeneous over most of the north Indian Ocean, reaching values close to global mean sea-level-rise trend (3.2 mm yr^{-1}) estimated over the same period. The only notable exception lies in the northern and eastern coasts of the Bay of Bengal, which experience larger trends (5 mm yr^{-1} and more). These recent trends derived from altimeter data are higher than those estimated from tide-gauge records over longer periods during the 20th century. This communication calls for an improved understanding of the mechanisms behind this accelerated sea-level-rise recorded over the past two decades, that could either be a direct response to global warming or a result from an aliasing by the natural variability.

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