Ecological Management Practices: A nature-based solution for Water and Sediment Yield from Urban Hilly Watershed

Presented by
Dr. Sagarika Patowary
Assistant Professor (WRE)
NERIWALM


Urban Flash flood
TRAVEL

Causes???

Extensive removal of vegetative cover caused by unplanned urban development

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Slope instability

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Soil erosion

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Less infiltration, more runoff

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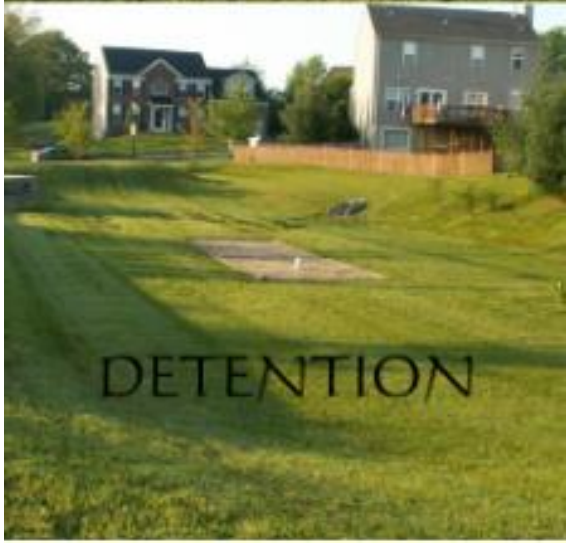
EMPs can be considered as an appropriate and competent urban watershed management practices if implemented appropriately.

EMP?



Hill-specific optimization model for EMP application

OPTEMP-CSMO (Sarma et al. 2013): OPTimal EMP model considering Carbon Sequestration with Multi-Objective optimization: aims to maximize the carbon sequestration and then, to minimize the EMPs cost.

OPTEMP-LS (Sarma et al. 2015): determines optimum allocation of EMPs in a hilly urban watershed to control sediment and runoff yield from watershed within a permissible limit but with a minimum possible cost.

R-OPTEMP-LS (Patowary et al. 2019): OPTEMP-LS by incorporating the **hill cut factor** in order to determine optimal combination of EMPs more accurately, based on GIS-based urban settlement estimation.

- Residential development in hills is associated with steep hill cuts, which are rarely visible in ortho-rectified satellite image.
- People prefer to live in flat land than in a raised platform in the form of a stilt house.

The **hill cut factor** assesses the steep hill cut area (associated with the residential development), which are rarely visible in ortho-rectified satellite images. (Patowary and Sarma 2018).

How to use this revised OPTEMP-LS?

Study area: Hills of Guwahati city

15 hills under *Guwahati Municipal Corporation Area* (GMCA) –

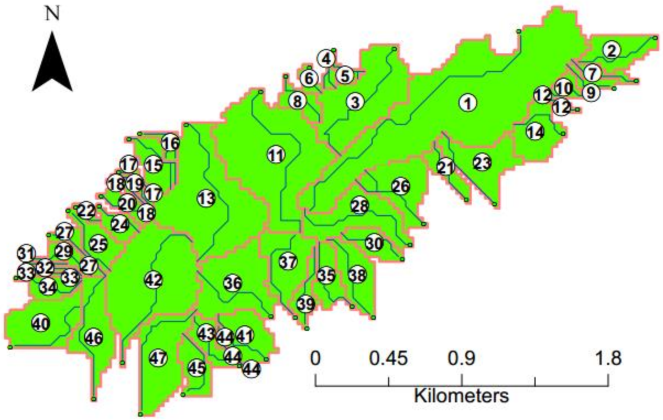
1) University 2) Fatasil 3) Kalapahar 4) Sonaighuli 5) Sarania 6) Kharguli 7) Japorigog 8) Burha-gosain 9)Khanapara 10) Garbhanga 11) Kamakhya 12) Kahilipara 13) Betkuchi 14) Chunsali 15) Koinadhara.

Burha-gosain, Khanapara, Koinadhara and *Garbhanga* hills *partly lie* in the study area (GMCA).

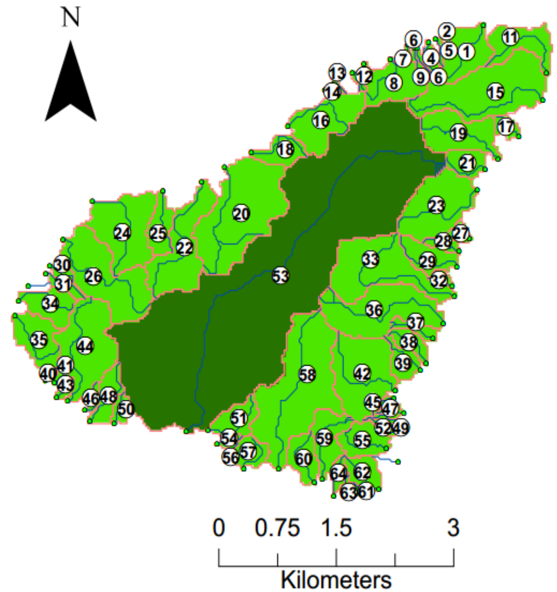
Total *watersheds* from 15 hills of Guwahati city = 612

Patowary, S. (2018). Projection of urban settlement in eco sensitive areas and its impact on watershed hydrology.

Peak runoff maps



Hill ID: 1 (2011, 2015, 2025)



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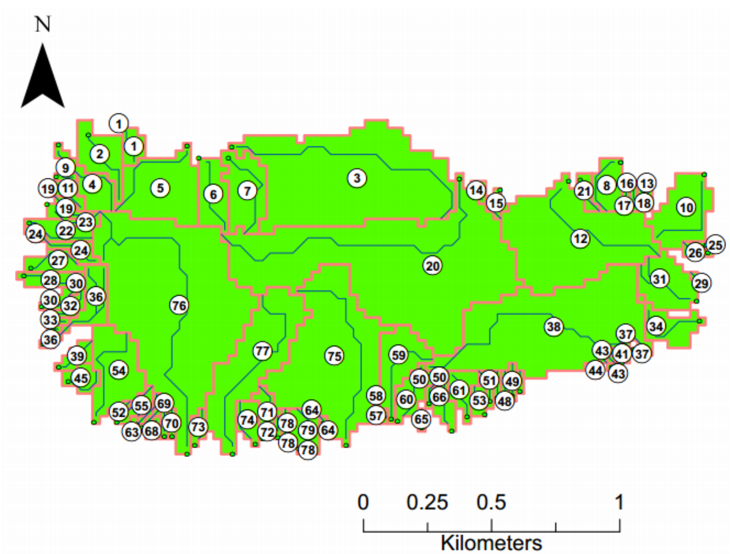

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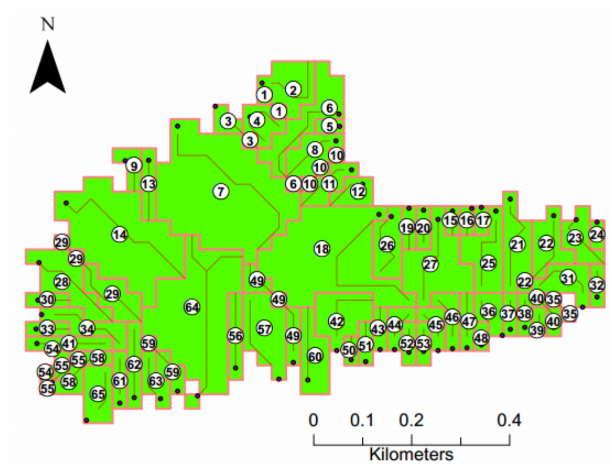

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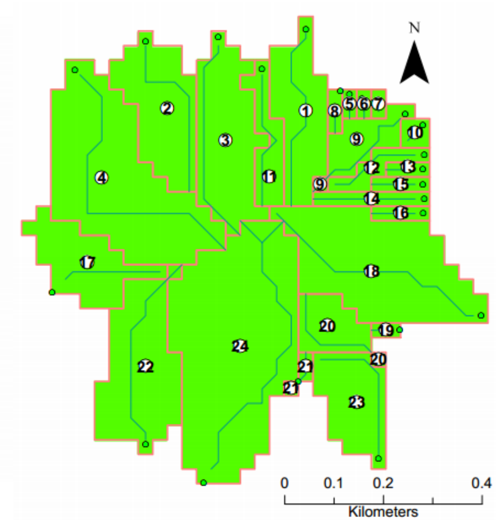
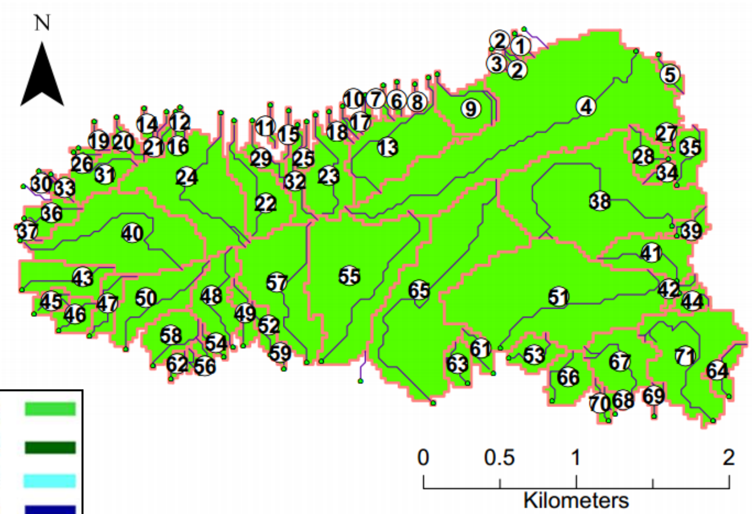


Hill ID: 5 (2011, 2015, 2025)

Peak runoff maps



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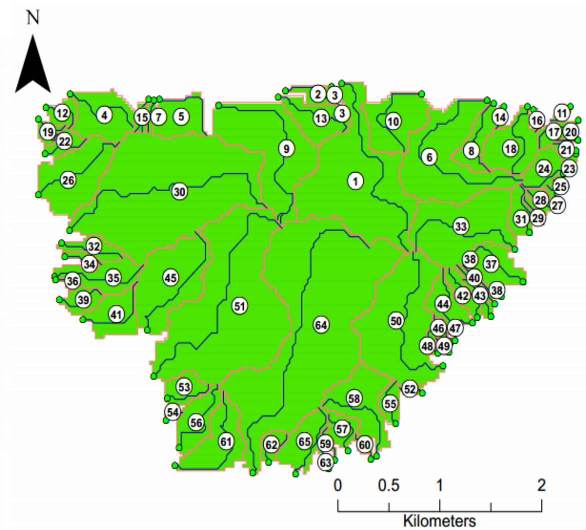

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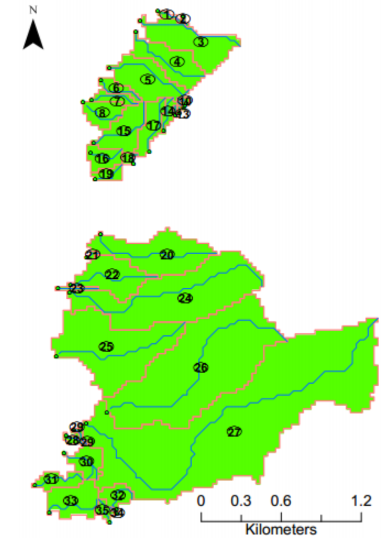

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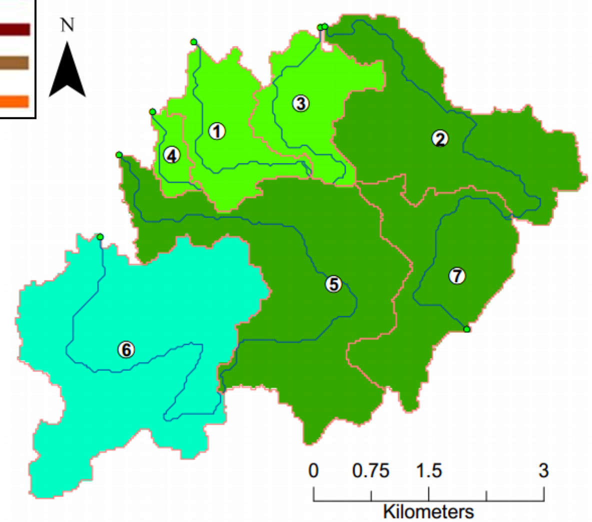

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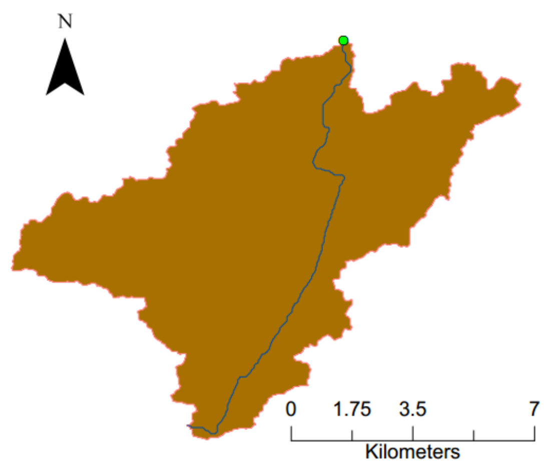
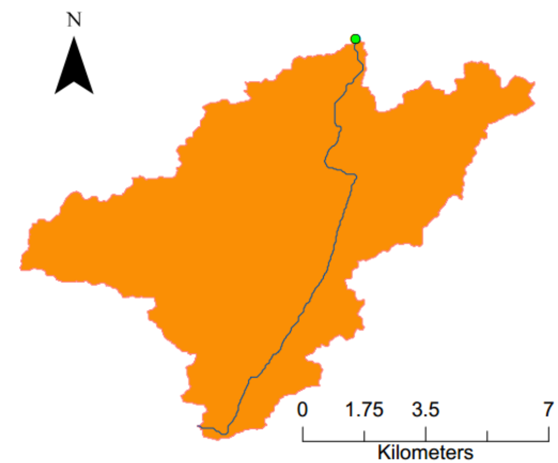
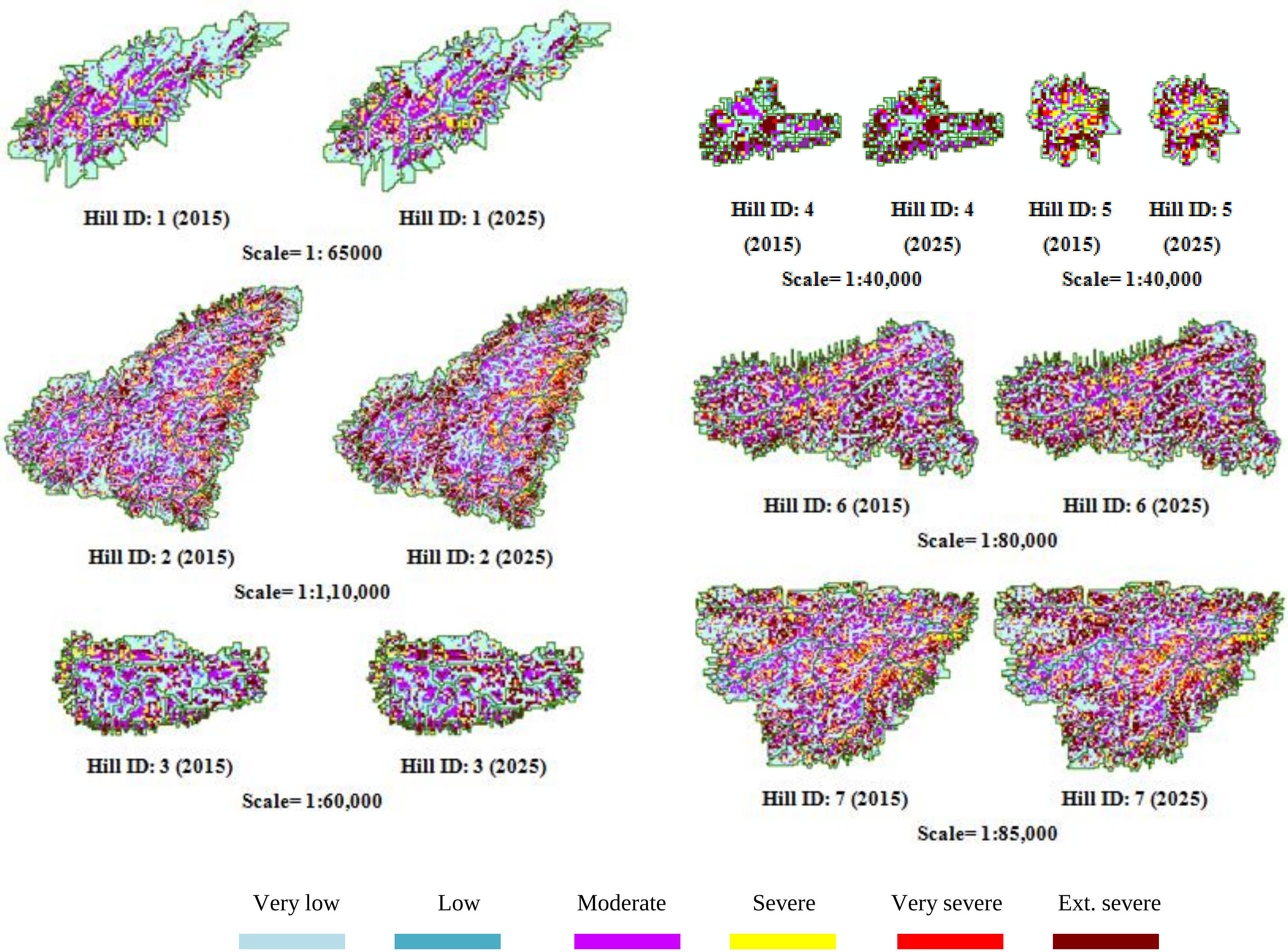


Hill ID: 10 (2011, 2015)

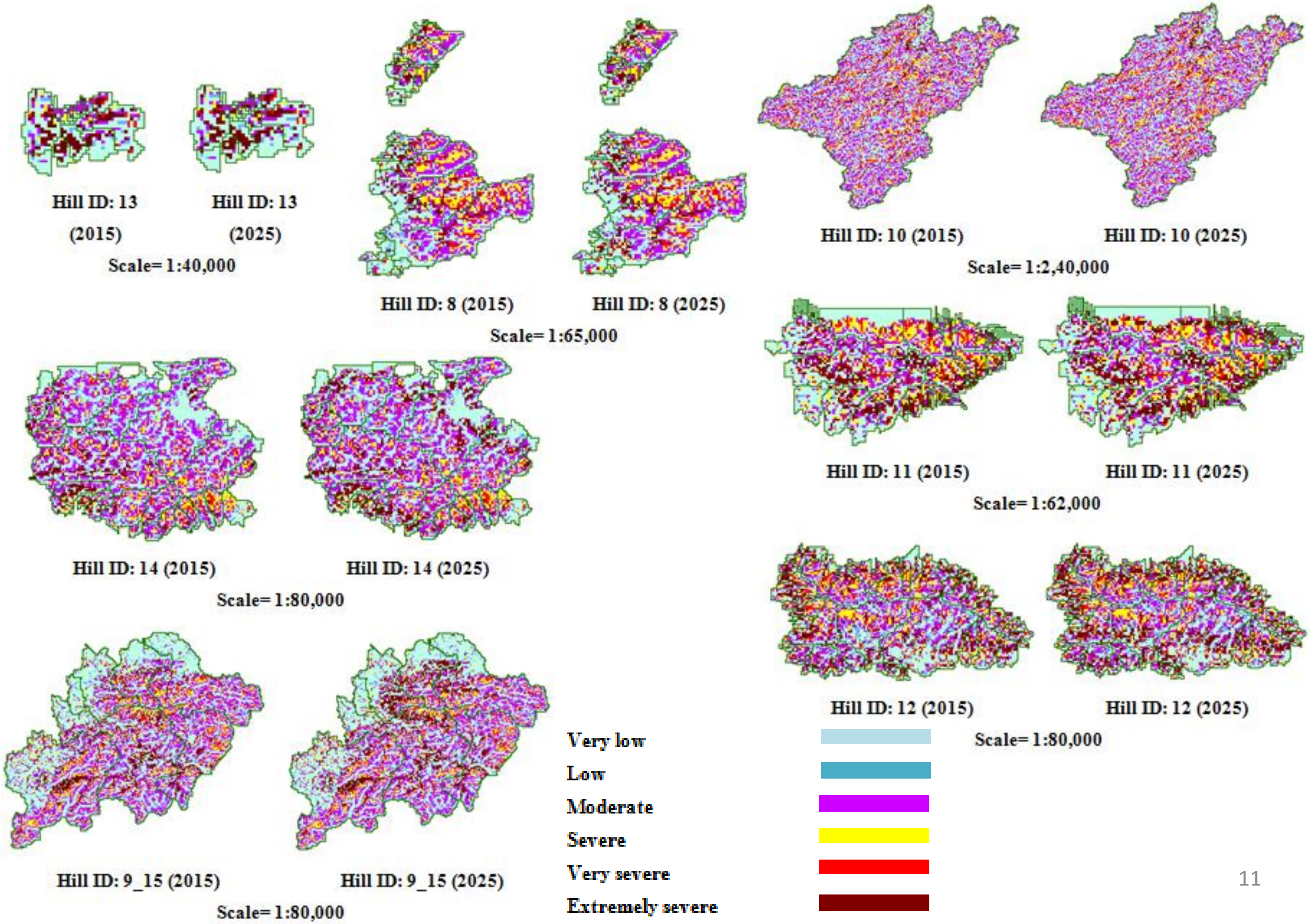


Hill ID: 10 (2025)

Soil loss maps

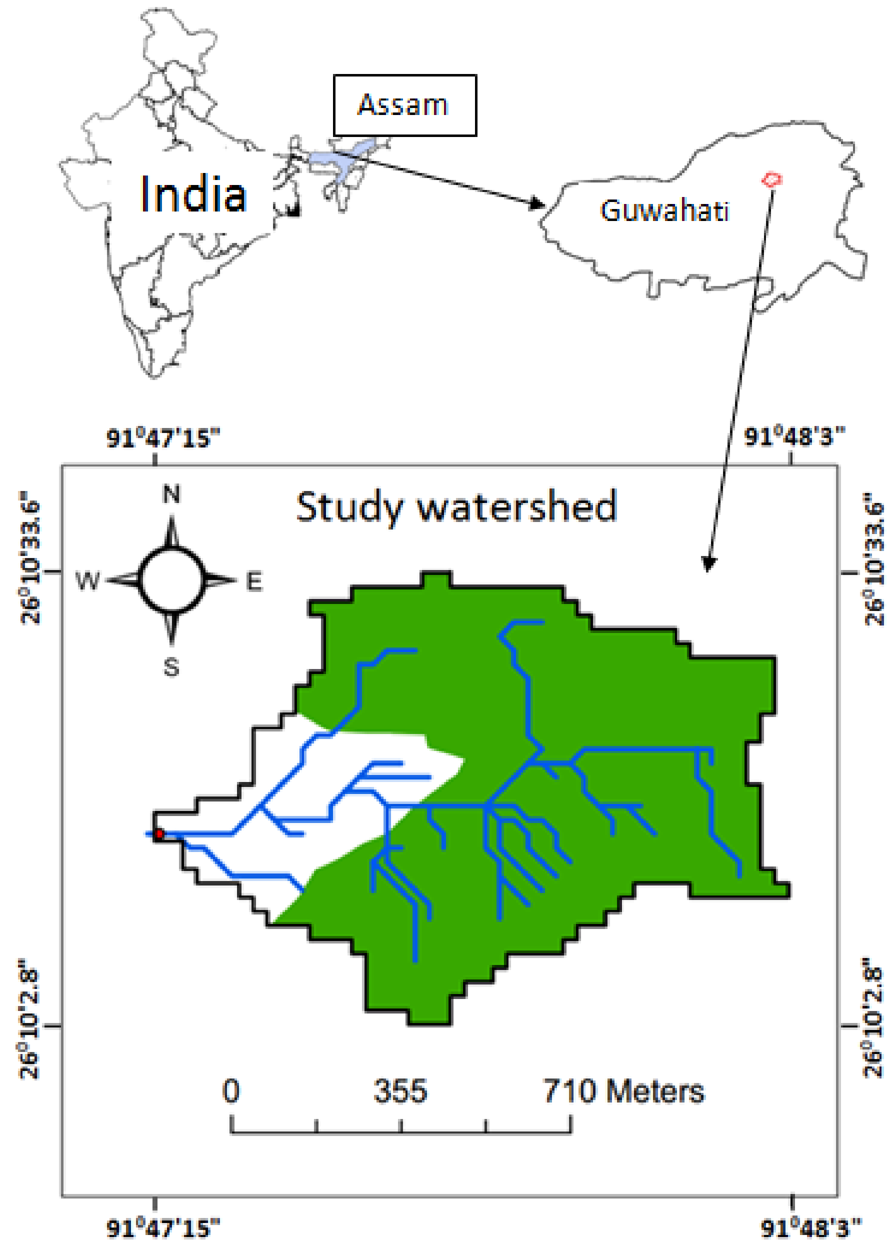


Soil loss maps

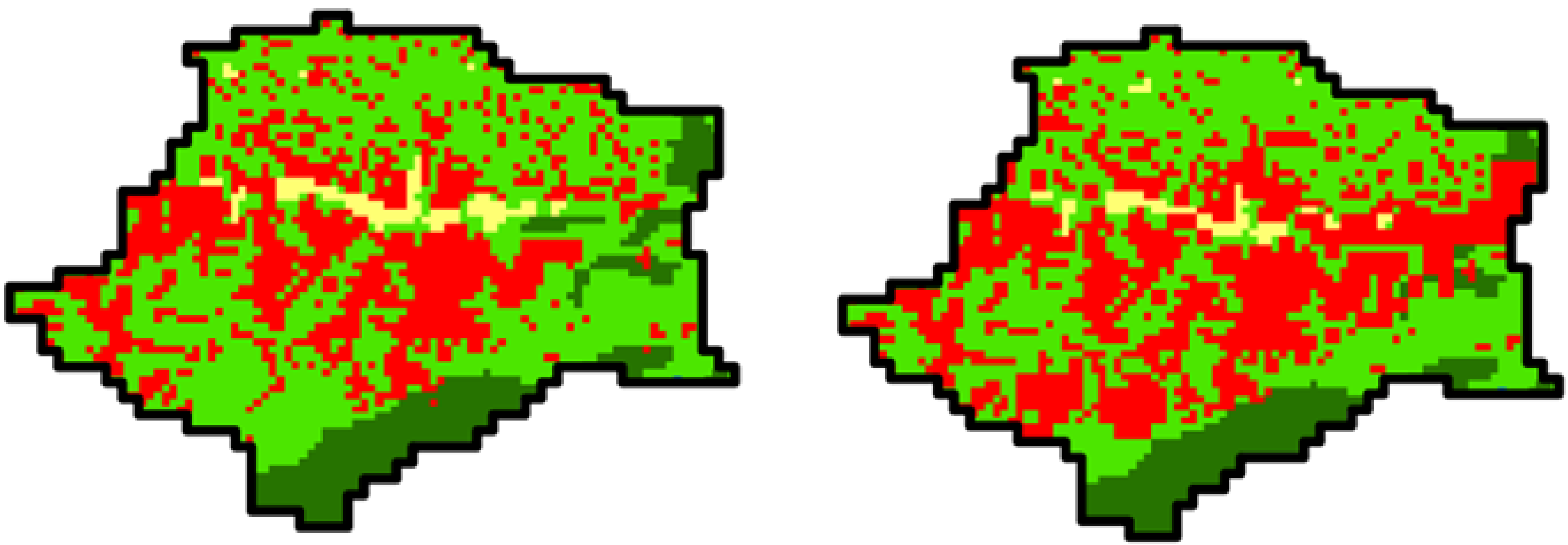


Location of sample watershed

- **Location of the study watershed:** Japorigog hill of Guwahati city.
- **Slope:** 0-32.9 degree (with an average slope of 14.17 degree)
- **Elevation:** 59 m -177 m.
- **Total area:** 74 ha, of which, urban settlement in 2015= 30.8% .(Patowary et al. 2019)



Urban settlement map



LULC (2015) **LULC (2025)**

LULC (2015) : LISS IV satellite image of 4 Dec 2015

LULC (2025) : Projected (Patowary and Sarma 2019)

: Scrub land : Forest : Marshy land : Bare land : Water bodies : Urban settlement

Patowary, S. and Sarma, A.K. (2019). Projection of urban settlement in eco-sensitive hilly areas and its impact on peak runoff. Environment, Development and Sustainability, 1-16.

Application of R-OPTEMP-LS model

✓ *The R-OPTEMP-LS model can be used*

- to determine the **optimum combination of EMPs** in a hilly urban watershed with **a minimum possible cost**.
- to control the sediment and runoff yield from the watershed within **a sustainable limit.**

➢ ***Objective function:***

$$\text{Minimize } Z = \sum_{i=1}^{n}(Cq_i + Cm_i)Xp_i + \sum_{j=1}^{q}(Cq_j + Cm_j)Xh_j + \sum_{k=1}^{r}(Cq_k + Cm_k)\,Yh_k$$

Xp_i = Area of the i^{th} EMP applied in plain area of the watershed (m^2).

Xh_j = Area of the j^{th} EMP applied in hilly area of the watershed (m^2).

Yh_k = Area of the k^{th} EMP applied in steep hill cuts of watershed (m^2).

i= 1, 2, 3, ..., n are the EMPs considered for the urban settlement area in the plain area of the watershed (grass, garden, forest, and detention pond)

j= 1, 2, 3, ..., q are the EMPs considered for the urban settlement area in the hilly area of the watershed (grass, garden, forest, and detention pond).

k=1, 2, 3, ..., r are the EMPs considered for the steep hill cuts associated with urban settlements in the hilly portion of the watershed (grass, and retaining wall).

Cq_i Cq_j Cq_k :Construction costs of i^{th}, j^{th} and k^{th} EMPs, respectively. (market rates 2012- 2013).
Cm_i Cm_j Cm_k:maintenance costs of i^{th}, j^{th} and k^{th} EMPs, respectively (market rates 2012- 2013)

Revised OPTEMP-LS model (Constraints)

- ***Sediment yield constraint:*** addressed by RUSLE.

$$S_{min} \leq S \leq S_{max}$$

S_{min} & S_{max} = minimum and maximum annual sediment yield required from the watershed (tonnes/yr);

S = sediment yield after the application of EMPs from watershed (tonnes/yr).

S_{min}= 0, S_{max}= $S_{natural}$=2608.79 t/yr,

- ***Peak runoff constraint:*** addressed by the Rational Method.

$$Q_{min} \leq Q \leq Q_{max}$$

Q_{min} & Q_{max} = minimum and maximum peak runoff required from the watershed (m^3/s);

Q = peak runoff after the application of EMPs from the watershed (m^3/s)

Q_{min}= $Q_{natural}$= 2.979 cumec, Q_{max}= Q_{drain}= 4 cumec

Revised OPTEMP-LS model (sediment yield constraint).....

$$S = RKLSP\,[C_c A_c + \sum_{g=1}^{u} C_{Lg} A_{Lg} + \sum_{i=1}^{n} C_{EPi} Xp_i + C_{uc}\left(A_{puc} - \sum_{i=1}^{n} Xp_i\right) + \sum_{j=1}^{q} C_{EHj} Xh_j + C_{uc}\left(A_{huc} - \sum_{j=1}^{q} Xh_j\right) + \sum_{l=1}^{t} C_{LSHl} A_{LSHl} + \sum_{k=1}^{r} C_{ESHk} Yh_k + C_{uc}(A_{shuc} - \sum_{k=1}^{r} Yh_k)]$$

C_c= Cover management factor for impervious area.

A_c= Impervious area in the watershed (m^2)

C_{Lg} = Cover management factor for g type of natural land cover in the watershed.

A_{Lg} = Area of g type of natural land covers in the watershed (m^2).

C_{EPi} = Cover management factor for i^{th} type of EMPs applied in plain area of watershed.

C_{uc} = Cover management bare/uncovered area in the watershed.

=bare/uncovered area in the settlement area of the plain watershed area (m^2).

A_{puc}= uncovered settlement area of plain watershed area

C_{EHj} =Cover management factor for j^{th} type of EMPs applied in the settlement area of the hilly portion of the watershed.

A_{huc} = uncovered settlement area in the hilly area of the watershed (m^2).

A_{shuc} =Area of bare steep hill cuts associated with urban settlements in the hilly area (m^2)

Revised OPTEMP-LS model (peak runoff constraint).....

$$Q = \left[R_{Cc} p_c U_{sw} + \sum_{m=1}^{u} R_{Cm} A_{Lm} + \sum_{i=1}^{n} R_{CEPi} X p_i + \sum_{j=1}^{q} R_{CEHj} X h_j + R_{Cuc}\left\{\left(1 - p_c\right) U_{sw} - \sum_{i=1}^{n} X p_i - \sum_{j=1}^{q} X h_j\right)\right\}\right] \times I$$

R_{Cc}= Runoff co-efficient for impervious area.

U_{sw}= Urban settlement in the watershed (m^2).

R_{Cg}= Runoff co-efficient for m type of natural land cover in the watershed.

R_{CEPi}= Runoff co-efficient for i^{th} type of EMPs applied in the plain area of the watershed.

R_{CEHj}= Runoff co-efficient for j^{th} type of EMPs applied in the settlement area of the hilly portion of the watershed.

R_{Cuc}= Runoff co-efficient for settlement area not having imperviousness i.e. bare/uncovered area in the watershed.

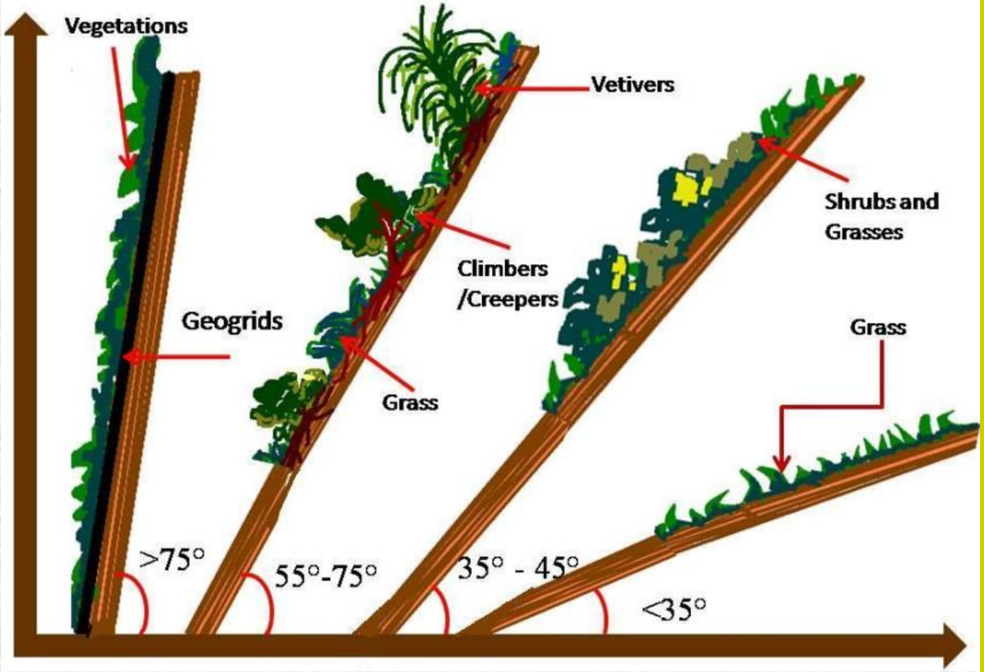
I = Rainfall intensity for the time of concentration of the watershed for a selected design storm (m/s).

Revised OPTEMP-LS model

- **Other Constraints**
- **Maximum area available for EMP:**

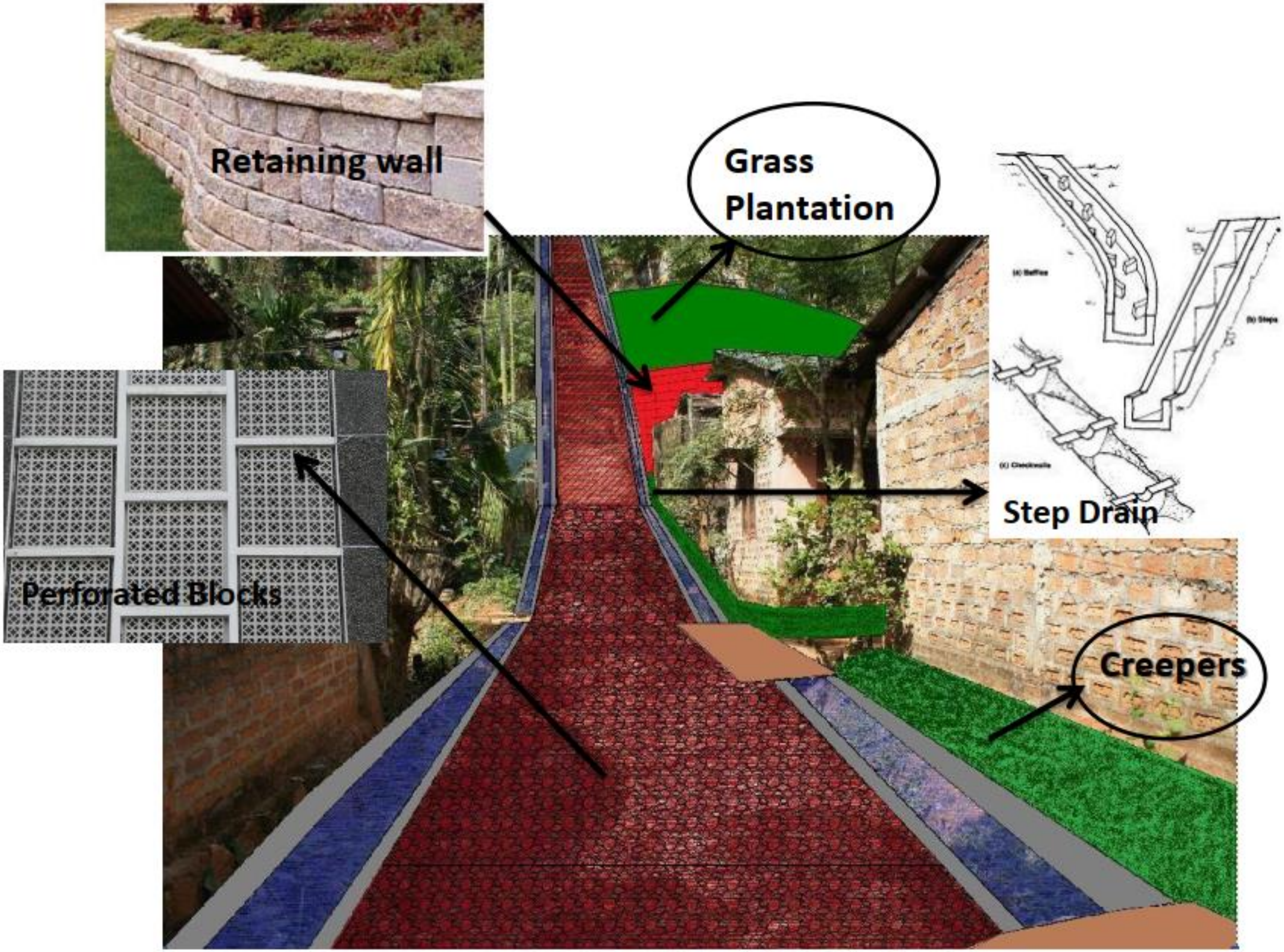
Total EMP area ≤ bare settlement area.

- **EMP area suitability constraint:** Minimum feasible area required for EMP ≤ Area of any EMP ≤ Suitable area available in the watershed for that EMP (Sarma 2011).



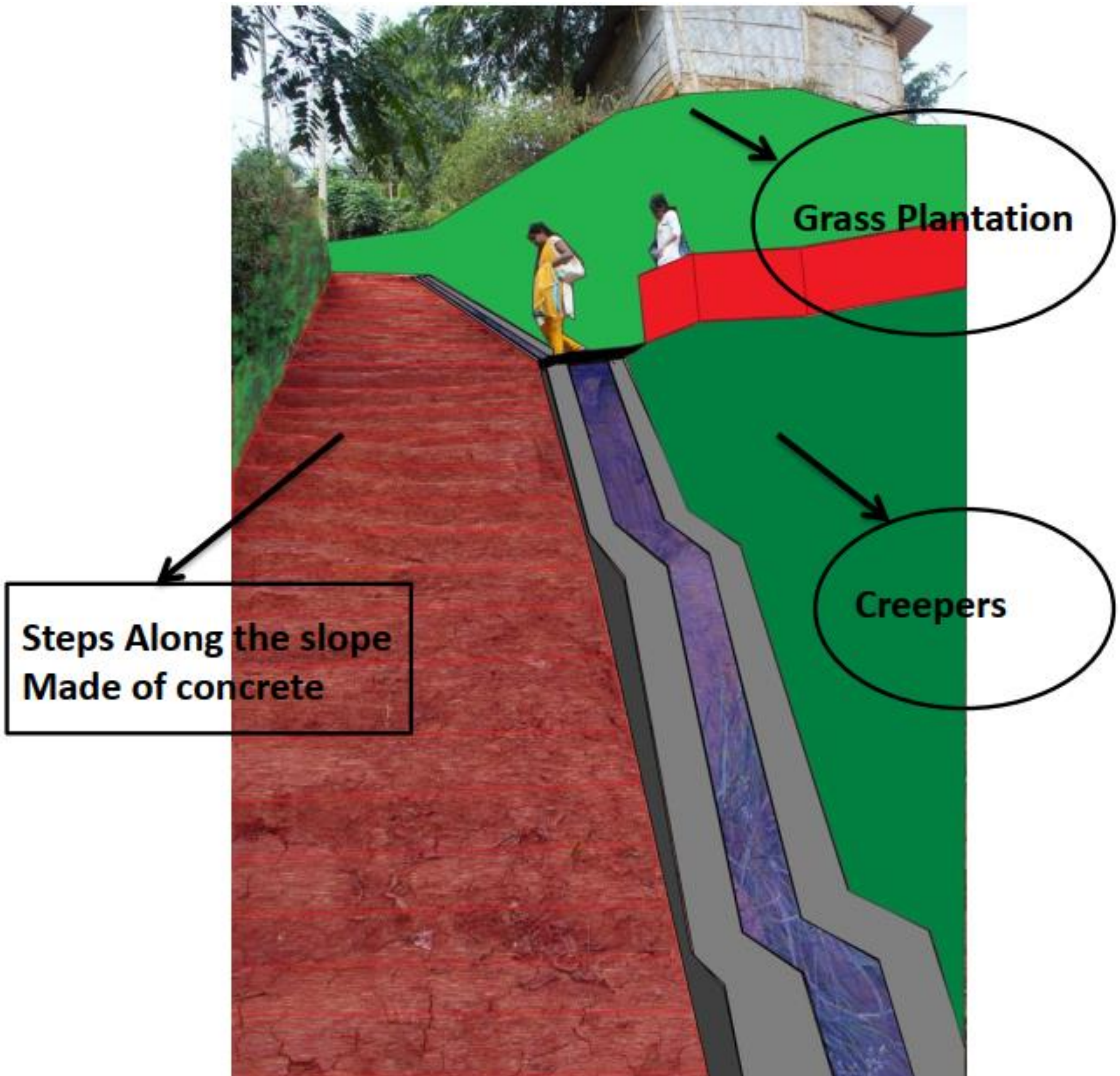
- **Owner's choice for EMPs:** The planned EMP area must be within the maximum and minimum limit of areas for that particular EMP as per the owner's choice.

Ecological Management Practices (EMPs) can provide nature-based solutions for reducing flood risks in a sustainable and economically viable manner



Source: CE Department, IIT Guwahati

Detail Planning in Already Developed Area



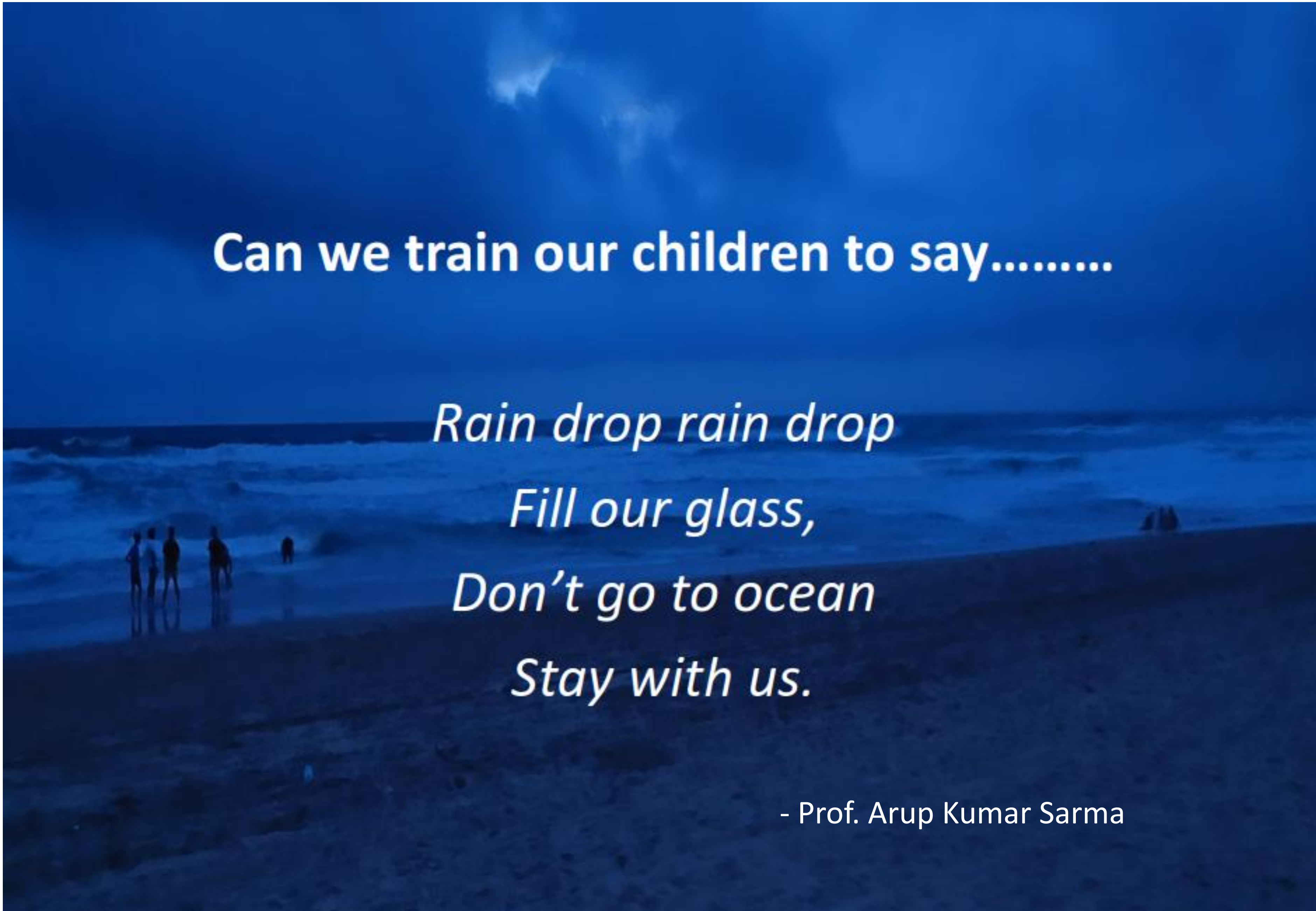
Source: CE Department, IIT Guwahati

Work Executed by GMDA on technical advice from IITG

Old road repaired and New Dra
step chutes

Roads with paver blocks and drain with step chutes

Source: CE Department, IIT Guwahati


Can we train our children to say………
Rain drop rain drop
Fill our glass,
Don’t go to ocean
Stay with us.
- Prof. Arup Kumar Sarma

References

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"Nature is not a place to visit. It is home."
—Gary Snyder

Thank you