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# The performance of green roof with storm rainwater runoff

Arun Pal [1] * , Dr Rajesh Sharma [2]

[1] *Lecturer --Department of Architecture, Government women Polytechnic ,Jodhpur Rajasthan-342001 India*
[2] *Assistant professor --Department of Architecture and town planning, Jai Narayan Vyas University ,Jodhpur Rajasthan-342001 India*

**Abstract**

*Storm rain water runoff is a major concern with urban areas. In urban areas the impervious surface likes rooftops, parking areas shopping areas and roads, paving, increase hazard of flooding due to storm water runoff. The reduction of rainwater runoff is a most significant and ecological improvement of green roofs .The main components of green roofs like vegetations, substrates and drainage layer influence the water retaining capacity as well as storm rainwater runoff. In the various types of green roofs water holding capacity varies 40% to 60% of total rainfall. It can be up to100% depending on the components of green roof system. Green roofs can retain all the small rainfall below 2 mm .Therefore it can reduce the hazard of flooding in urban area .Green roofs can improve the quality of storm water runoff comparative to the conventional roofs .It can absorb contaminants of heavy metals up to 90% of rainwater and filter the pollutants. Due to particular attribute of storm water retaining ,it can reduce possibility of combined sewage overflow and expenditure correlated on its occasion. Green roofs can reduce magnitude of nitrate and phosphate of rainwater runoff. Green roof can reduce up to 54% of rainwater runoff of individual building .The rain water retaining ability of green roofs is lower in winter than summer season. Green roof is an important tool to reduce rainwater runoff in urban area.*

***Keywords*** *----: Green roof; Rain water runoff ; Storm water management; Urbanization; Water quality ; Bio char; Rock wool*

## 1. Introduction

It is investigated that in the last 20 years, flooding the most incessant type of catastrophic event [5]. It has expanded around the world. Rainfall in urban areas is commonly more hazardous cooperative to rural areas, on account of more impenetrable surfaces, for example, rooftops of buildings, shopping areas, parking lots , roads [9]. In the urban region the dominance of impenetrable surfaces and structures make specific issue because of storm rain water runoff [5][19]. In the developed and under developing countries urbanization is increasing rapidly [3]. In most made urban regions, rooftops may exit to around 40-50% of the impermeable urban surface range [5]. It is expected to reach 83% in 2030 [United Nation, 2002] [3].The impervious surface like rooftops, parking areas, roads and shopping areas are increasing storm water runoff [4]. It is estimated that 10 % of housing development and 71 % to 95% of shopping and industrial areas covered with impervious surfaces in U.S.A. [Fergus, 1998] .So green lands are decreasing and impervious surfaces increasing continuously. Thus increase the possibility of flooding and reducing infiltration into the ground water system [4][Barnes et al.,2001]. There are shortages of urban hydrological systems [White,2002] [3].Therefore during raining events a large quantity of storm rainwater runoff may be causes of flooding [Environment Agency,2002][Villarreal et al.2004].To reduce storm water runoff we require ponds ,reservoirs [Ferguson,1998] and green roofs where water can store and evaporate [3].Green roofs can play active role to balance the biodiversity in urban area [Van Herzela and Wiedemann]. In the rainy period storm water rapidly comes outside of the building .Due to this storm water runoff may be hazard of flooding in urban area [White, 2002]. So nowadays rain water management is a serious concern especially in urban area [1]. The Best Management Practices (BMP) of United State has included slowing the flow of water, open channels, wetlands and green roofs [Dunnnet and Clayden, 2007].Green roofs are the one of the most important tools for storm water management and also create lack of green land in urban area [1]. For the effective storm water management in Oregon city according to strategy for the impervious surface area more than 46.5 $m^2$ of a building, developer has to provide provision for storm water management or he has to pay fee to municipal for storm water management [Liptan, 2005]. Green roofs can play an important role to reduce storm water runoff comparative to typical impervious roofs [Carter and Jackson, 2007].It is

investigated that intensive green roofs of 15 cm substrate depth can retain 75% of annual rainfall and extensive green roofs substrate of depth 10 cm can retain 45% of annual rainfall [Van Woert et al, 2005].In general the reduction of runoff range varies from 50% to 100% depending on the components of green system like depth of substrates, slope, intensity of rainfall and types of vegetations [3].

## 2. Process of runoff water

There are different capacities to decrease water overflow with the assistance of green rooftops. (a) The pores of substrate can absorb water (b) Plants can retain water in plant tissues and remove into the atmosphere (c) Evaporation of water from the surface of plants [Dunnett and Kingsbury, 2008].

### 2.1 Variables of water runoff in green roof

Water runoff is depends on the design of the green roof like slope of roof [Getter et al., 2007 ] ,depth of growing medium [Vanwoert at el.,2005], structural components of green roof [Berndtsson ,2010] and intensity of rainfall ( graph-2-3) [Mac Millan ,2004] .

**Table-1** Rainwater retention of green roofs with various rainfalls [Hilten et al, 2006]

| Rainfall amount | rainfall retention (green roof) |
|---|---|
| 1.27 | 100 % |
| 2.54 | 65.6 % |
| 3.81 | 44.0 % |
| 5.08 | 33.3 % |
| 7.91 | 21.6 % |

It is investigated that variety of plants influence water runoff reduction from green roofs [1]. To get optimum performance of green roof regarding water runoff, the selection of appropriate plants is very essential [Dunett et al., 2008].Hilten (2006) investigated that quantity of water runoff from green roofs depend on amount of rainfall as shown table –1 [10].

**Table --2** Water runoff according to seasons

| Roof type | winter season | summer season |
|---|---|---|
| conventional roof | 86% | 70% |
| Green roof | 70% | 52% |

There are number of factors can effects water retention efficiency. According to season water runoff efficiency can change (table-2) and In winter water retention (90%) is higher than summer seasons (53%) [Mentens et al,2006]7].

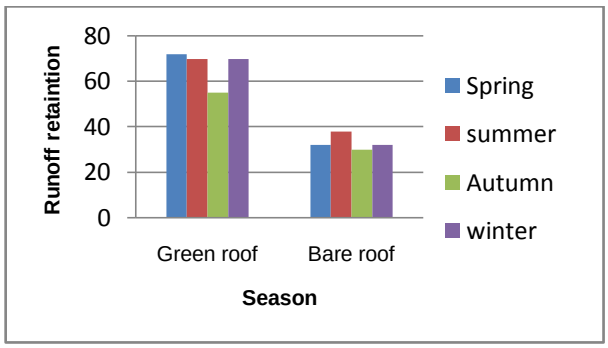
**Table-3** (Villarreal et al, 2004)

| Slope of geeen roof | rainfall | runoff water retaintion % |
|---|---|---|
| Slope 2% | 24mm | 62% |
| Slope 8% | 24mm | 43% |
| Slope 14% | 24mm | 39% |

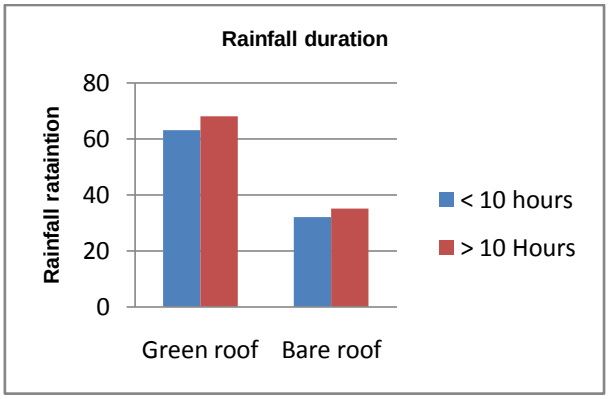
Slope of green roofs is another important aspect (as shown table-3) [Getter et al,2008] [7] that effect the water retention performance. The slope green roofs 2% and 7% are most significant (graph-5) [4].

**Graph-1**



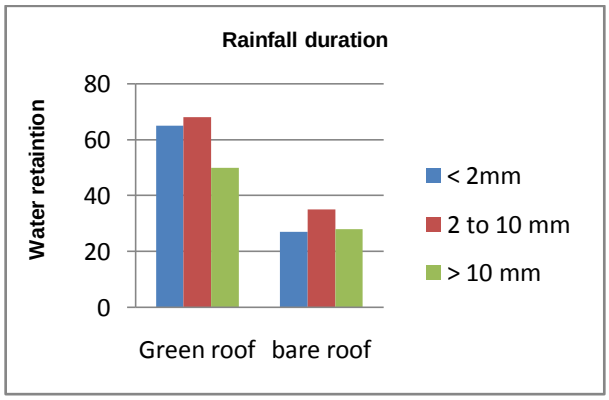

Rowe (2005) observed that green roofs are very efficient for water retaining comparative to bare roofs [14].Villarreal (2004) examined that if the slant of green rooftops are $2^0$, $8^0$, $14^0$ separately, Author watched when precipitation power was 0.4 mm/min water retention esteems were 62%, 43%, 39%, if rainfall was .8mm/min retention values were 54% ,30% ,21% [11]. Organic stuffing in substrate increment water holding efficiency [7]. Age of green roof is a considerable effecting feature, due to substrate properties change over time the organic materials and macro pore creation by the roots of plants that increase the water retention capacities of green roofs [getter et al,2007][7].

**Graph -2**




J.Mentens (et al.,2005) explored the yearly water runoff for customary rooftop was 91% and 15% for intensive green rooftop. The quantity of water runoff varies according to seasons (Graph-1) [Villarreal et al.,2004].

**.Graph -3**



The water retaining capacity in summer season always high because of high evapotranspiration rate from green roof [3].Speak et al,2013 examined normal water retention for intensive green rooftop was 65.7% and in paved rooftop 33.6% [7].

### 2.2 Koehler formula

Water runoff from green roofs depends on type of plants, type of substrate, transpiration procedure. The water holding ability of a green roof explained by the following manner [Koehler, 2004]. Water runoff = precipitation – [water interception +water retention + transpiration of plants+ evaporation of soil] [1].

### 2.3 Plants

Plants can absorb the water in plant tissues and these water moves to atmosphere through transpiration [18]. Several fractions of water store on the surface of plants it move to environment during evaporation [1-2].Water holding capacity of plants depend on the surface area and structure of surface area like taller plants can hold more water comparative to small plants like mat formatting [1].Extremely intense roots of plants can hold least water because or a smaller amount porosity in substrates [Maclvor and Lundholm,2011]. According to photosynthetic mechanism plants are separated in different types.C3 plants (belong to most common types of plants),C4 (belong to mat formatting plants like grasses and crassulacean acid metabolism (CAM) plants,C4 plants demonstrate high transpiration rate and its growth rate is high [Larcher ,2003 ].Nagase and Dunnett (2012) investigated that the amount of storm water runoff decrease 23% to 38% if we planted grass rather than sedums [5]. Dunnett,(2008) investigated that taller plant can decrease more runoff [7].

### 2.4. Substrate

In the storm water runoff the type of substrate and depth (shown table-5) participate most considerable role in green roofs [Stovin et al,2012][17] .In general the grass species can play very significant role at decreasing of water runoff [1].Ayako and Nigel et al ,2011 investigated that bare soil can absorbs more water comparative to vegetation species roofs .Sedum species is just exception [15].

**Table-4** effects of bio char in water runoff

| Soil type | rain fall retention | study |
|---|---|---|
| Green roof | 17.8% | D.E.Beck et al,2011 |
| Green roof with bio char | 21.1% | D.E.Beck et al,2011 |

Due to storm water runoff the amount of nutrients in green roofs decreases. Thus for the suitable cultivate of vegetation appropriate nutrients in substrates are essential [15]. Bio char demonstrated expanded water retention capacity ( table-4) and critical reductions in release of aggregate, nitrogen, phosphorus, nitrate phosphate and organic carbon. Both phosphorus and nitrogen are fundamental supplements for plants development. There is a need to locate a fragile harmony between giving adequate supplements to sound plant development while at the same time diminishing filtering of supplements in the overflow [15].

**Table-5** Water runoff according to substrate layer depth [J.Mentens et al.,2005]

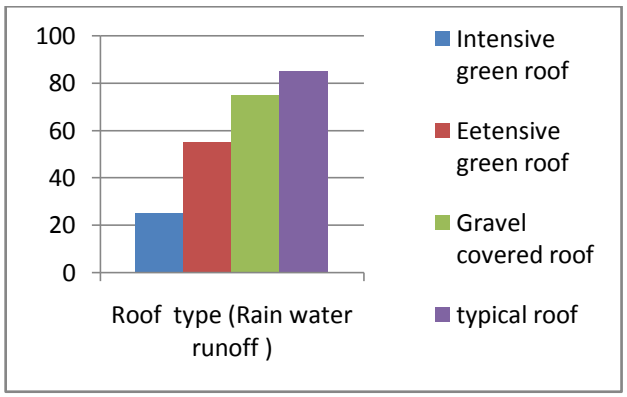
| Type of roof | substrate layer depth | water ronoff |
|---|---|---|
| Intensive roof | 210 mm | 25% |
| Extansive roof | 100 mm | 50% |
| Gravel covered | 50 mm | 76% |
| Traditional roof | --------- | 81% |

To create the balance, deficiency of nutrients in substrate of green roofs matrices is called bio char [Glaser et al,2002]. Utilization of bio burn as a dirt added substance in green rooftops has some appealing points of interest [15].After adding bio char in substrate of green roofs the water retention capacity was observed 78% ,61% water retention observed without bio char [15]. Expansion of 7% bio char by weight to the soil can reduce quantity of water runoff and improve its quality [D.E.Beck et al,2011][15].

### 3. Role of green roof

Green rooftops are progressively being utilized as a source control measure for urban storm water administration [11]. In the UK, green roofs are progressively being perceived for their part as Sustainable Urban Drainage Systems [White and Alarcom, 2009][7].




**Graph-4** Annual water ronoff of diffrent types of roofs

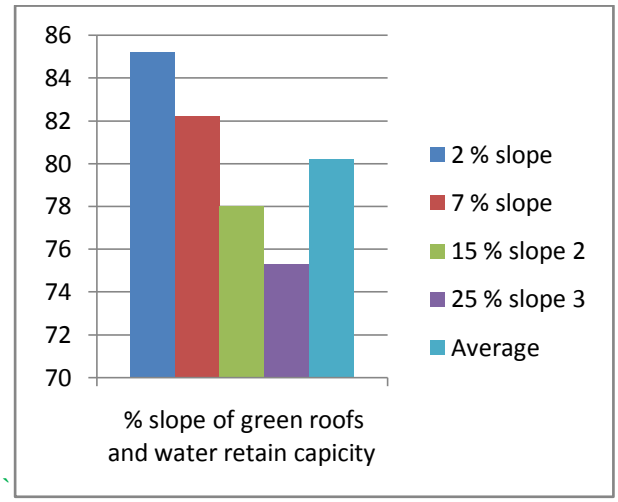
Green roofs typicality take form of a carpet of plants [5].It do not require extra land [5].Green roofs retains storm water [4].The green roof system have plants substrates layer and drainage layer [Mentens et al.,2003].The green roofs can play following important role: (a) decrease storm water runoff [4] (b) postponement the original time of water runoff due to absorption of water in green roof (c) hold the water runoff for long time [3] (d) reduce effect of urban heat island [Bass et al.,2000].(e) can reduce energy cost for cooling and heating [Takakura et al. 2000].(f) create habitats for wildlife [Overndorfer et al,2007], reduce air pollution[Speak et al,2012][7].A general idea of yearly rain water surplus presented in graph -4 [3].Green roof increase life of roof and air quality [Banting et al.2005],include aesthetic worth and develop the biodiversity [English Nature.2003][5].It reduces urban heat island [Sailor,2008][5]. Intensive green rooftops, with their more profound substrates and higher plant biomass, can hold more prominent amounts of runoff comparative to extensive green roofs [7].Overall water retention efficiency of intensive roofs double comparative to bare roofs [7]. Green rooftop offers a sustainable solution of storm water runoff [17].

Impervious surfaces increase the ambient temperature, urban heat island, noise and decrease air quality, biodiversity .Green roofs are the one of the important tool to reduce negative effects of these problems [4]. Peak, [2005] investigated that in Toronto city 6% of buildings have green roofs. It would result in a similar tempest water maintenance affect as a building a $ 60 million storage room [Deutsch et al.,2005]. Green rooftops can hold 80.2 % of water for all slants. For little rain it can hold 90.2% and for substantial up to 63.3% .Water maintenance esteem for the 2% slant of green rooftop is 85.2% and for 25% slant 75.3% [4].

Rockwool is regularly introduced between the waste and substrate layers to enhance water maintenance limit of green roofs. Rockwool perform as a reservoir as well as complementary substrate coating .Due to high water retention limit of shake fleece can give the extra advantage of improving vanishing cooling in green rooftops [Jim and Tsanget al 2011][17].

**Graph -5**




In Germany average extensive green roofs have yearly water retention range 50% with 100 mm substrate and 75% for intensive green roofs with 210 mm depth of substrate. It requires very low maintenance [5].Low and heavy rain effects the water retention capacity of green roofs (table-6) [5].Sedum green roofs can reduce annual water runoff up to 50% through evapotranspiration [11] ,Kohler, (2002) investigated value 60-79% [11]. Scholz Berth,(2001) claimed value 75% [11].

**Table-6**

| Rain type | depth of substrate | water retention |
|---|---|---|
| 2mm (low rain) | 20mm | 96% |
| 6mm (heavy rain) | 20mm | 52% |

There are some study done by different authors (table-7) about water retention efficiency of green roofs. .It is investigated that 10%-35% volume reduction in wet season [Liptan et al.2003][5].Green roofs can decease the toxic waste from storm water runoff due to filtration and absorbing the pollution this pollution [9].

It is investigated that green roofs are sink of nitrate nitrogen and ammonium nitrogen. It is examined that concentration of nitrogen, phosphorus compound and heavy metals was lower in urban water runoff [8].The concentration of heavy metals like Fe,Pb,Zn in water runoff from intensive roofs decrease comparative to bare roofs [8].In storm water runoff presence of heavy metal like-Cd,Fe,Ni,Pb,Zn, are hazardous for health [20].

## 4. Water quality of storm water runoff

When the storm water comes outside of building collects the oil, salts, heavy metals, pesticides and animal waste .After applying the green roofs we can decrease these contaminate water and combined sewage overflow .It can also decrease expenditure associated to its storm water runoff management system .The age of green roofs can control runoff of water quantity [2]. Steusloff [1998] investigated that extensive green roofs can keep hold 92% to 99% of heavy metals and Cu 34% ,Zn 72%, Cd 62%, and Pb 91%.It is investigated that during the acid rain event the concentration of N and P measured lower compared to bituminous roof in storm water runoff [Teemusk and Mander,2007].Water runoff of conventional roofs are more pollutants compare to green roofs [Ammann et al.2003][15].This runoff water have heavy metals like cadmium and zinc [Thomas and Greene et al,1993][15].

Green roofs are the natural sink of ammonium nitrogen and nitrate nitrogen. Overflow water quality from vegetated rooftops is a significant ecological angle specifically if vegetated rooftops are joined with open storm water systems [8].

**Table-7**

| Water retaintion green roofs | various study |
|---|---|
| 45% - 70% (annual) | Kolb et al.,2005 |
| 60% | Moran et al,2004 |
| 100% | Johnston et al,2004 |
| 66% | Voyde et al.2010 |
| 65.7 %(average annual) | Speak et al,2013 |
| 45% (extensive roofs) | Mentens et al,2003 |
| 60% (extensive roofs) | Moran et al,2003 |
| 60% (extensive roofs | VanWoert et al,2005 |
| 90% (extensive roofs small rain) | Carter and Rasmussen et el,2006 |
| 75% (extensive roofs) | Mentens et al,2006 |
| 100% (small rain) | Simmons et al,2008 |
| 43% (heavy rain) | Stovin et al,2012 |
| 82% | Voyde et al,2010 |
| 85.7 (small rain 2.1mm) | mander et al,2007 |
| 92% (small rain 1.3) | Carter and Rasmussen et al,2005 |
| 39% (heavy rain 5.4) | Carter and Rasmussen et al,2005 |
| 72.6%(small rain< 2mm) | Wong and Jim et al,2014 |
| 36.8%( medium rain 2-10mm) | Wong and Jim et al,2014 |
| 15.7%(heavy rain >10mm) | Wong and Jim et al,2014 |

It is regularly accepted that vegetated rooftops would add to overflow water quality as compare to bare rooftops overflow [English nature, 2003] due to evapotranspiration [Getter et al, 2007][8]. In this manner, expecting similar conditions of contaminations from a vegetated rooftop and a hard rooftop, yearly pollutant quantity from a vegetated rooftop would be less [8].It is investigated that amount of $BOD_7$,COD,N,P were higher in water runoff of bare roof comparative to green roof (table-8) [9].

**Table-8 -** Water quality runoff [9]

| Indicator | water ronoff | bare roofs | green roofs |
|---|---|---|---|
| pH | heavy | 5.62 | 7.85 |
| $BOD_7$ | heavy | 2.9 | 2 |
| P | heavy | .012 | .090 |
| $PO_4$ | heavy | .004 | .036 |
| $NH_4$ | heavy | .22 | .35 |
| $NO_3$ | heavy | .18 | .42 |

Kohler and Schmidt (2003) investigated that during the raining pH of substrates increase [9]. Storm water overflow is an imperative fare vector for nitrogen that has amassed in urban conditions [Davidson et al,2009][13].

## 5. Conclusions

Concerning the adequacy of green rooftops to reduce storm water and these are very successful for little rainfall (<2 mm).The green roofs play significant role in storm water retention .Its value can decrease as well slopes increase. For green roofs 2% slope has most significant value. In the aged green roofs due to organic contents water retention efficiency increase. Season and rainfall quantity play an important role in water retention. Intensive green roofs improvement on 10% of the working in Manchester city downtown zone would grow yearly rain water runoff by 2.3%.Vegetated rooftops should not be seen as an instrument for enhancing overflow water quality by decrease centralization of toxins found in rainfall. The outcomes demonstrate that a green rooftop can effectively hold light rain occasions. Bio char in the substrate of green can increase water retention efficiency of green roofs and improve quality of water runoff .

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