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AUGMENTATION OF THE URBAN GREEN INFRASTRUCTURE USING STORMWATER SURFACE RUNOFF AS A RESOURCE IN THE NICE EXPRESSWAY, KARNATAKA, INDIA

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Highlights

- This study charts down the path a designer has to look into a road design from a 360 degrees point of view rather than looking from one direction only.
- This study is about saving ecological systems, improving microclimates and sound implementation of design practices for the betterment of people and the nature around them.
- The models proposed here are a base study for an expressway/highway in India and any other country considering the city's climatic conditions.
- The surface runoff that goes just down the drain when channeled and utilized can serve as one of the best resources to the ground water table.
- The models proposed here are a start of safety ideas and reduction in accident fatalities that need to be looked into.

Abstract. Urban areas, characterized by impervious surfaces, produce storm water runoff which during unexpected heavy rainfall exceeds the carrying capacity of the storm water drainage system causing urban flooding. Transport expressways are massive hard-scaped surfaces generating large amounts of polluted surface run-off during the rains. In the case of the Nandi Infrastructure Corridor Enterprises (NICE) Expressway at Bengaluru, India, which is also a tolled road, the demonstration is about using the surface run-off or stormwater as a resource for developing urban green infrastructure complementing the transport grey infrastructure. The functions of urban green infrastructure include air quality improvement, microclimate modification, storm water management, biodiversity, recreational opportunities and visual aesthetics. Here we show, that the surface runoff or stormwater is effectively channelled to the areas around, to mark the beginning of a well-planned and executed drainage system, maintenance-free landscape and technically a sound, urban green infrastructure in the form of site-specific models of Rain Gardens. The same models can be used in other transport expressways as they are the indicators of economic growth and connectivity although would require to be customized as per the city and its climatic conditions. This paper explores three different scenarios with a typical model of development of green infrastructure along the transport expressway tailormade for each of the situations. While in the first and the second models, the Central Rain Garden and the Edge Rain Garden have been respectively proposed, the third model explores a comparatively complex scenario in the form of an Intersection Rain Garden.

Keywords: expressway, grey infrastructure, storm water management, green infrastructure, rain gardens, landscape management, visual aesthetics.

Introduction

Transport expressways, in India, are strong indicators of the economic development of regions within the country that need to be connected with high-speed roads for motorized traffic only. They are different from other similar highways and arterial roads as they as transport facilities carry only relatively large vehicles like cars, buses and trucks. Expressways are not generally accessible by vehicle categories such as bullock carts, cycles, two-wheelers and three wheelers that typify traffic in India. The NICE Expressway, when fully completed, connects Bengaluru, Karnataka state capital and IT Hub, and Mysuru, an important historical city of the state. It is a private expressway and a

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toll road developed as a Build, Own, Operate and Transfer (BOOT) project. The NICE expressway, in its present fully completed and operational section is extensively used by goods vehicles as well as patronized by passenger vehicles including private cars and buses. These vehicles while adding to the pollution of the air, surface and water only are an additional factor considering the fact that the expressway has not been envisaged with integrating landscape design and biodiversity in the process.

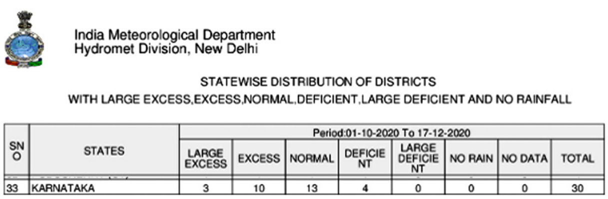
1. Objectives of the study

This study has been done to explore the resource potential of grey infrastructure surface run-off or stormwater for augmenting urban green infrastructure while proposing rain gardens as options for enhancing visual aesthetics (Siwiec et al., 2018; Fletcher et al., 2015). The surface run-off water into traditional storm water drains and nearby lakes or ponds carrying surface pollutants only contaminate the water therein. If channelled and constructed well considering all the aspects of the site, the rain garden would only prove to be beneficial in the long run charging the groundwater table also in the interim.

1.1. Significance and justification of the study

The NICE Corridor Expressway has only upon study shown that grass and few short to medium sized shrubs are growing in the study area. With large amounts of the polluted surface runoff water running to the traditional storm water drain, not only would the existing lakes and water bodies in the vicinity typically get contaminated but the immediate ground water table also would start depleting with no recharge of the same in the long run. The maintenance of the grass and lawn grown in the median of the expressway serves no purpose functionally or aesthetically with labour for regular maintenance as an additional overhead. The long drive over the study area has also shown a lack of safety for the vehicle user towards the central median and no visual aesthetic component attached to the drive. A change in the typical road section introducing the concepts of Rain gardens would only enhance the existence, sustenance and continuance of the Expressway.

In Figure 1, we can see data received from Indian Meteorological Department (IMD) for a period of two months from October to December 2020, wherein the average rainfall for the state is in excess and normal in most of the districts on a broad perspective.


India Meteorological Department
Hydromet Division, New Delhi

STATEWISE DISTRIBUTION OF DISTRICTS
WITH LARGE EXCESS,EXCESS,NORMAL,DEFICIENT,LARGE DEFICIENT AND NO RAINFALL

SNO	STATES	Period:01-10-2020 To 17-12-2020							
		LARGE EXCESS	EXCESS	NORMAL	DEFICIENT	LARGE DEFICIENT	NO RAIN	NO DATA	TOTAL
33	KARNATAKA	3	10	13	4	0	0	0	30

Figure 1. Rainfall data for Karnataka

1.2. Scope of the study

The NICE Corridor has a running 111 km Expressway between Bengaluru and Mysuru wherein the study area has been located for approximately 8.21 kms in length between 12°51’00.75” N, 77°35’03.67” E, elevation 932 m and 12°51’34.87” N, 77°39’13.95” E, elevation 917 m. The scope of the study area starts after the Toll Plaza at Bannerghatta Road and terminates before the Toll Plaza at Hosur Road. Crossing through some noticeably sized lakes like the Meenakshi Lake, Gottigere Lake and the lake at Chikkathoguru, this study validates the proposal of the Rain gardens to serve as a model for not only the remaining length of the NICE Corridor but also any other expressway in the country, considering the city and its climatic conditions.

1.3. Limitations of the study

Rain Garden with its benefits of improving the ground water quality, increased water retention capacity when compared to lawns, nevertheless has to be constructed correctly to avoid waterlogging and flooding. Improper construction of the same will only lead to water stagnation and breeding of mosquitoes thereby. Also, the selection of plant species, considering the location and climatic conditions of the proposed Rain Garden, should be carefully done. This if done incorrectly, will only lead to either a high maintenance landscape or a barren urban desert, both being counterproductive to the entire process. This study assumes the following:

- Ground work has been done with careful consideration of the slopes and selection of plant species, before the installation of the rain garden and that basic maintenance of the Rain Garden would be carried out post the execution of the same.
- Team handling the execution and maintenance have a working knowledge of the various terminology associated with the design as given in Table 1.

2. Review of literature

2.1. Environmental impact

Runoff water is an important transporting medium for various pollutants from land to surface water (Ambade, 2014; Schmitter et al., 2016; Burns et al., 2012; Carlson et al., 2015). The rain runoff water washes out the air as well as land pollutants and flushes out into water bodies which is very common in urbanized and industrial cities of India (Ambade, 2014). Although the rain garden cannot be a replacement to the traditional storm water drain system, it’s successful execution can help in the reduction of total rain water runoff and of its peak for the study area (Basdeki et al., 2016). The mitigation of the indirect pollution of the lakes and water bodies in the vicinity of the study area can certainly be reduced by the rain gardens (Müller et al., 2019). In the runoff process, pollutants from the vehicular emissions on land

Table 1. Key definitions and concepts

Term	Definition adopted
Expressway	In Indian terminology, an expressway is defined as an arterial highway for motorized traffic, with divided carriageways for high-speed travel, with full control of access and usually provided with grade separators/ interchanges at location of intersections. These are six or eight-lane highways with only fast-moving vehicles plying on them
Gray Infrastructure	Structures such as buildings, roads, utilities, and parking lots. Gray infrastructure is impervious, forcing water to run off, which must be managed and cleaned before and eventually entering rivers
Green Infrastructure	Areas covered with trees, shrubs and grass. Green infrastructure is porous, allowing rain to soak into soil, which recharges ground water and naturally filters pollutants before entering rivers (Fletcher et al., 2015)
Storm-water Management	Storm-water management means to manage surface runoff after rainfall. It is essential in urban areas where run-off cannot infiltrate because the surfaces are impermeable
Rain gardens	A rain garden is a garden of native shrubs, perennials, and flowers planted in a small depression, which is generally formed on a natural slope. It is designed to temporarily hold and soak in rainwater runoff that flows from the surrounding impervious surface in urban areas
Bio-retention areas	Bio-retention areas are shallow landscaped depressions which are typically under drained and rely on engineered soils, enhanced vegetation and filtration to remove pollution and reduce runoff downstream. They are aimed at managing and treating runoff from frequent rainfall events
Visual aesthetics	Visual aesthetics refers to beauty or pleasing appearances of not only things but views and vistas also
Storm-water Management	Storm-water management means to manage surface runoff after rainfall. It can be applied in rural areas (e.g., to harvest precipitation water) but is essential in urban areas where run-off cannot infiltrate owing to impermeable surfaces. Traditional storm-water management was mainly to drain high peak flows away. Unfortunately, this only dislocates high water loads. Modern approaches aim to rebuild the natural water cycle, i.e., to store runoff water (e.g., retention basins) for a certain time, to recharge ground water (e.g., infiltration basins) and to use the collected water for irrigation or household supply. Costs depend on technology and the size of the systems. Planning, implementation and operation and maintenance require expert knowledge

also penetrate the ground contaminating the groundwater, a source of freshwater to man's drinking and farming requirements in forms of dug wells and borewells (Taebia & Droste, 2004; Nixon & Saphores, 2007). Groundwater is an important source of drinking water and plays a critical role in the realization of the human right to water (Pawari & Gawande, 2015; Malus, 2005). Contamination of this groundwater by surface runoff water is a rather slow process that eventually spreads from one region to another thus affecting the entire system underground. Groundwater recharge, with less pollutants, is a sure way for avoiding groundwater depletion in the long run (Nixon & Saphores, 2007; Smith, 2002).

Even in developed countries, the rain garden, considered one of the low impact techniques, can prove to be cost efficient rather than upgradation of the existing sewer networks (Basdeki et al., 2016; Hunt & White, n.d.). The Rain Garden with its native plants is a start in the cleaning and recharging process of the biodiversity of the region (Zhang et al., 2020). Plants through the process of phytoremediation are also known to absorb the pollutants pushed to the soil by the surface runoff. These plants help in the breakup of certain toxic compounds present in the pollutants to the basic level (Hunt & White, n.d.). Although this is a long process, it is better in the first place to keep a check on the vehicular emission of pollutants considering the safe levels. This method using the "tolerant plants" has become in recent years one of the safest ways to detox the environmental contamination of the ecosystems (Paz-Alberto & Sigua, 2013). Compared to soil washing, a costly technique to clean the contaminated soils, the installation of a working rain garden is a cost-effective, ecologically friendly and a natural way to help clean up the soil before the pollutants penetrate the soil (Tangahu et al., 2011).

2.2. Health and safety impact

In continuation of the environmental impact of the groundwater, the incidence of fluoride above permissible levels along with the presence of heavy metals have been found in many states including Karnataka (Kumar & Shah, 2006). Various diseases and health issues affecting all in terms of short-term like viral infections and diarrhoea have become widely rampant over the last few years while long-term diseases like cancer, methemoglobinemia, fluorosis and arsenicosis have all started taking prominence (Krishnan & Indu, 2006; Nixon & Saphores, 2007). The reduction of pollutants reaching the soil and the groundwater is ascertained by the usage of carefully selected native plants that are proposed in the rain garden.

The NICE corridor expressway has met its fair share of criticism with numerous accidents happening in it. Long stretches of flat landscapes with no change in the scenery with drivers behind the wheel at high speeds has been attributed to the issue of "Highway Hypnosis", a key factor for causing accidents and affecting the safety of the users of any highway or expressway. A common phenomenon, as seen in Figure 3, when the driver behind the wheel of the vehicle goes into a trance-like mode while driving is when several hundreds of metres do not have changes in the landscape scene with monotonous colours or forms

Figure 2. Crash barrier or guard rail not proposed on Central Median

appearing the entire drive, in a way hypnotising the drivers. This when coupled with fatigue due to driving over long hours or sleepiness, only leads to accidents (Cerezuela et al., 2004).

The expressway in the study area does not have any barricades on the edges or towards the central median in the form of vehicle crash barriers or guard rails. As visible in Figure 2, large goods vehicles and four wheelers at high speeds losing control towards the central median not only affect themselves in the crash but can also head towards the other side of the roads with no prominent landscape acting as barriers. The landscape treatment in the central median with only a bare patch of a grassed surface acts as an easy drive over for the vehicle losing control as can

Figure 3. Phenomenon of "Highway hypnosis" experienced

Figure 4. Unsafe flat patch in the central median

Figure 5. Issue of safety for the working staff

Figure 6. No safety barricades around

be seen in Figure 4. The proposed Rain Garden with its edge treatment with natural boulders in the central median slows down the vehicle when it is crashing and the continuous, undulating forms of the boulders only act as a deterrent in creating still landscapes.

With such a mismanaged intent of the grass patch in the central median, the maintenance for the same, as seen in Figures 5 and 6, clearly indicates the danger the working staff need to face to clean it up. With no safety barricades, the staff is at the mercy of the oncoming speeding vehicles to notice them and not lose control. When landscape design is proposed in edge conditions or the central median design in highways, analyses have shown to positively reduce the fatalities for both vehicles and pedestrians (Antonson et al., 2009). Studies showing that manicured landscapes are preferred over unkempt vegetation (Wolf, 2018) which is quite evident in the entire study area. The proposal also aims to reduce the negative effects of induced stress on the urban commuters of this route by the introduction of the green route. Maintained landscapes seen during driving would not only calm the drivers and in turn the traffic but also reduce the possibility of the number of fatalities in this expressway.

2.3. Aesthetic impact

Aesthetics for an expressway is highly required considering it connects cities and towns across a state. Being of such high weightage as the primary connector of regions, its aesthetics are of utmost importance. People driving regularly to office and those of the large goods vehicles require a pleasant, long drive away from the urban traffic and crowd. While driving can be considered a stressful activity, the lack of a scenic landscape with no prominent landmarks or changes in the scenery, only aggravates the driver on an expressway (Guo et al., 2019). As in Figure 7, broken kerbs serving as a median separator between the incoming and outgoing road lanes with no prominent signage at access points only confuses the new user entering this expressway.

Bare, half-grown patches of grass are clearly visible proving to be an eyesore to the user on this road. With no kerbs acting as separators between the road and the

Figure 7. Lack of signage with no clear demarcation of the roads

Figure 8. Missing kerbs at the edge

Figure 9. Missing kerbs at the central median

grass, poorly planned landscape design at the edges and in the central median take the centre stage of aesthetics on this road as seen in Figures 8 and 9.

As seen in Figure 10, the central median with a part green patch of grass and its other portion as a barren land is a definite blemish in the urban landscape for a well-known cosmopolitan city like Bengaluru. Going against few of the Gestalt Principles of Perception, the aesthetics herein does not conform neither to the Law of Similarity nor the Law of Symmetry and Order. With a haphazard visual design and none of the visual principles followed throughout the study area, the user while driving is unable to have an overall enriching experience as clearly evident in Figure 11.

The missing visual aesthetics of the expressway is analysed in terms of absent landmarks or key elements that hold the attention span of the driver. In the lines of Gestalt's Law of Continuity, the proposal of having one key plant species called a "Marker Plant" in the central median regularly at the change of a kilometre over the 8 km long study area, identifies itself as a landmark. Landmarks by their pure existence structure environments and form cognitive anchors or reference points (Richter & Winter, 2014). The "Marker Plant" adds to the quality of the entire highway landscape and hypothesizes that it is not just a "quantity" to the vegetation (Fumagalli et al., 2020). While the reaction time to open landscapes on straight roads has been noted to be longer than those of enclosed landscapes (Guo et al., 2019), the driver can nevertheless note the introduction of the new plant species once a kilometre thereby not losing focus on the road ahead.

Figure 10. Poor visual aesthetics with unfinished patches

Figure 11. Broken, unfinished guard rails at edge

2.4. Rainfall and runoff: connected components in the hydrological cycle

Runoff in simple terms can be defined as the amount of rainfall that falls on the ground and gets carried away or essentially that "runs off" the surfaces to transport the fallen water into abutting lakes or reservoirs or the ground in itself. The importance of connectivity between rainfall and runoff could simply mean how runoff reaches the water bodies, evaporates over time to form rain clouds, return as rain and so the cycle repeats (Keith, 2012). While the hydrological process might sound very simple when put like above, the aftermath of disasters pertaining to rain and floods need be forecasted in advance with simulated models (software programs) putting them in use in advance to warn people and prepare them along with their governments for evacuation or transferring them to safety. It is inevitable to fail at times in predicting the strength of natural calamities like tsunamis or cyclones in even developed countries wherein functioning advanced warning systems always help a significant percentage of the population towards their safety and protection (Zhang et al., 2020; Suppasri et al., 2013; Kates et al., 2006). Severe natural catastrophes like flash floods or cloudbursts might not usually be an annual occurrence in urban cities but unprecedented storms and heavy downpours in tandem with poorly designed or overworked drainage systems causing havoc to the residences and their access roads haphazardly built-in close proximity to lakes and low-lying areas with issues of water logging, flooding and ensuing power cuts is a regular scene disrupting people's lives intermittently (Elaji & Ji, 2020).

Rain gardens being one of the types of the infiltration-based technology pose as a feasible solution in urbanized areas where rainfall runoff is considered valuable to be captured and integrated into the urban water cycle rather than being disposed of as just "wastewater" or "drain water" (Zhang et al., 2020; Fletcher et al., 2015; Schmitter et al., 2016). Rainfall runoff presents itself with the aid of technology as an additional source of water, better biodiversity, effective recharge of the groundwater table and improved microclimate. Engineering fields pertaining to hydraulics and hydrology with technological improvements have over the last few decades found to play significant roles in prediction and calculation of runoff for aiding better designs pertaining to the effective usage of rainfall (Fletcher et al., 2015). Prediction of water quality draining into catchment areas along with momentary changes owing to events like storms and floods have become the quintessential feature of any rainfall-runoff research model.

Before the advancement of computers and technology, physical hydraulic models were commonly used by designers which were eventually replaced by conceptual and statistical models that were based on mathematical and computational analysis (Chadalawada et al., 2020). The Rainfall-Runoff models are a simplified form of the real time scenarios represented by Hydrological models/mathematical models that are basically qualified into two groups namely the Deterministic models and the Stochastic models (Keith, 2012; Galkate et al., 2014). Hydrological models are tied to the physical processes going in a hydrological cycle connecting various variables, initial conditions and set parameters and they become very essential to assist in making informed decisions about rainfall patterns, impending flood scenarios or rains thereby mitigating their disastrous effects. Deterministic models are generally built on the principle of only one outcome based on defined preset given parameters while stochastic models bring in the inherent uncertainty that occurs in reality thus presenting different outputs every time although there are sometimes overlaps between the said models in their methodology and output (Keith, 2012; Galkate et al., 2014).

Few important model types pertaining to the Rainfall-Runoff modelling can be associated with the Rational Method, Black Box models, Regression models and the Unit Hydrograph (Keith, 2012). Widely used models like the Rational Method, Soil Conservation Services (SCS) Curve Number Method and the Green-Ampt Method play significant roles when it comes to flood forecasting, pollution control and water resources planning (Zhang et al., 2020; Galkate et al., 2014). Conventional rainfall runoff models face problems in the fact that they do not look in depth into the latest problems arising with the effects of change in land use and land cover owing to agricultural practices, forestry, pollution and toxic wastes released into water bodies (Elaji & Ji, 2020). To overcome this issue, physically-distributed models like the European Hydrological System – Systeme Hydrologique European or SHE model and IHDM deal effectively with the changes in land cover and land use or in drainage patterns in catchments (Herath et al., 2020).

When it comes to prediction of water quality, a framework of integrated modelling and monitoring in hydrological and hydraulic modelling is a key aspect. Nature of the water reservoir as freshwater or marine/salt waters also requires to be kept in mind in the model simulations considering the variations in their salt content, nutrient cycles and dynamics of the inherent ecosystem to name a few (Wang et al., 2019). Integrated frameworks tend to be inclusive in their nature seamlessly encompassing methodologies of hydraulic and hydrological modelling, water quality modelling with datasets and data assimilation techniques. These support in better prediction accuracy, impacts of discharges into the water bodies, control of water contamination and foreseeing the changes in water quality when affected by events. Integrated frameworks, not only in design, but from a monetary standpoint need to be sustainable when proposed for a scenario. While uncertainty and flexibility go hand in hand in design of the water management system, the same concept is pertinent to be used in investments also considering the avoiding of the risks and working on increasing the gains in the lifetime of the project.

Advanced approaches in flexible monitoring and prediction can be associated in recent decades with a powerful machine learning technique called Genetic Programming (GP) proposed as a modelling and forecasting tool, although a recent introduction to the field (Chadalawada et al., 2020; Herath et al., 2020). GP being a latest addition to a highly emerging sub field in computer science called Evolutionary Computation, works on the lines of its parent's theories. These theories proposed are primarily based on nature and its evolution (biological science) abetting the methodologies so derived in the formulation of rainfall-runoff models. Just as in nature where the fittest of a said species survive and evolve over years to hunt better, live longer and think clearly thus making them the best in the environment to grow and multiply, GP works on the principles of creating solutions for complex engineering problems infused with random and chaotic variables as in reality. The end result of such a tool over iterations of selection, cross over and mutation as in nature ultimately brings out the best fit model. GP "grey box" models are comparatively interpretable and simple in their functioning helping the designers to modify as the process progresses compared to data mining prediction models or "black box models" (Herath et al., 2021).

Designers in fields of hydrological and hydraulic engineering along with the allied fields of urban water management need to research the above-mentioned concepts in depth to analyse and predict sustainable and workable models/solutions that decision or policy makers need to consider for long term perspectives (Wang et al., 2019). These models without the expert's knowledge or the specialist's inputs will be a sure cause of monetary failure along with losses in terms of manpower, time and effort for the project (Chadalawada et al., 2020).

3. Methodology

3.1. Description of study area

The Study area is an entirely enclosed and gated one with ingress and egress of vehicles being regulated at the toll plazas. It is interesting to note that the expressway passes through urbanized areas, agricultural fields as well as natural spaces and areas. It is both an urban form and grey infrastructure with its wide expanse of impervious surface which during the rainy season creates the surface run-off or storm water.

3.2. Research approach and design strategies

The study aims to exploit the resource potential of stormwater/surface runoff through rain gardens. Rain gardens generally are planted with native and local plant species. This is done since native species require less maintenance, consume less water, have a good root system and most of all are non-invasive. Invasive plant species dominate large areas of land quickly, do not act as soil binders, replace the native species at a very fast pace and overall affect the biodiversity of the region. This in turn causes a chain reaction in affecting the wildlife and loss of habitat for many species of insects, animals and birds thus adding them to the Endangered List. While a rain garden is going to remain dry in many of the months owing to dry season or drought conditions, the proposed plant species would have conditioned themselves to the climatic conditions of that region over many centuries (Grehl & Kauffman, 2007). Altering this with no standard logic or reasoning is a long-term catastrophic effect on the region's flora and fauna at the microlevel. Plants chosen for the proposals include those that are native or local which have acclimatized themselves over the years to the city's climatic conditions. The "Marker Plants" have been identified specifically as those helpful in Phytoremediation with an ornamental quality also aiding in visual aesthetics. Grasses and shrubs proposed have been considered to not affect the line of sight for the driver from any height or distance. The "Marker Plants" have been chosen with a height of an average 1.2–1.8 m to maintain uniformity in form and function over the study area.

The Design Strategy can be applied in the study area in one of the proposed models based on the scenario as defined case wise in typical situations shown in Table 2.

There can be three commonly seen scenarios in a highway which have been the points of consideration for developing these Models.

Scenario 1: Edges of the roads are left untreated which can be seen in Model 01: Edge Rain Garden (Figure 12) wherein the edges after the hardscape treatment of the roads are well designed to take care of the surface water and pollutants.

Table 2. Proposed Design Strategy for each model

S. No	Model number	Name of model	Location of model
1.	01	**Edge Rain Garden**	Along the edges of the expressway after the Road Shoulder with a calculated slope of diverting the surface runoff water towards the edges
2.	02	**Median Rain Garden**	In the central median of the expressway
3.	03	**Intersection Rain Garden**	In the road intersections or junctions

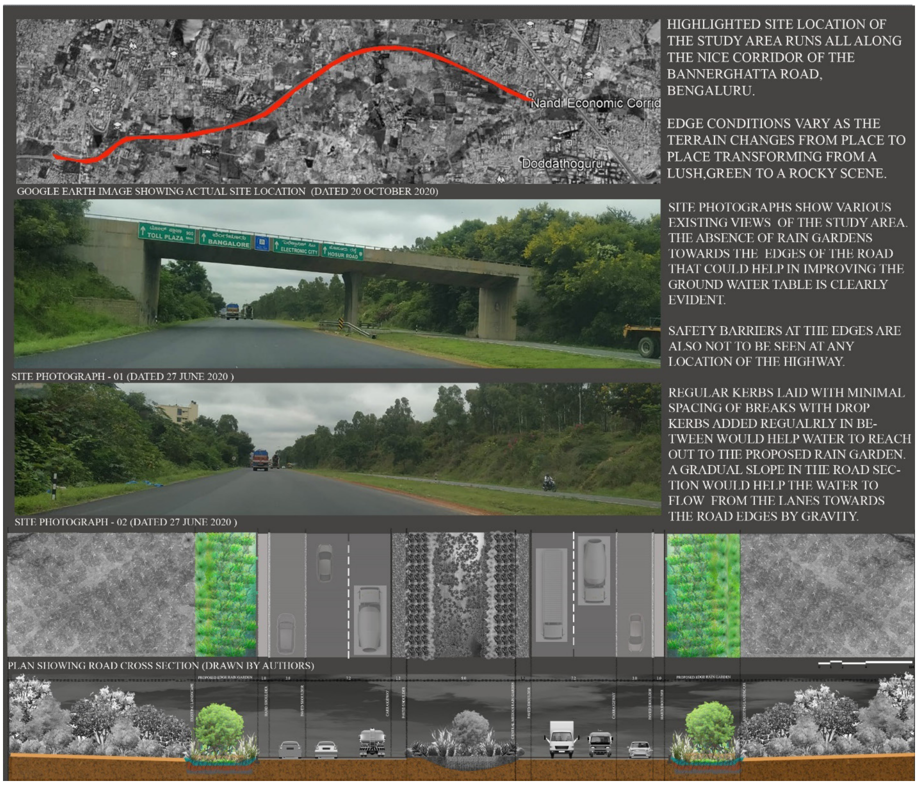


Figure 12. *To be continued*

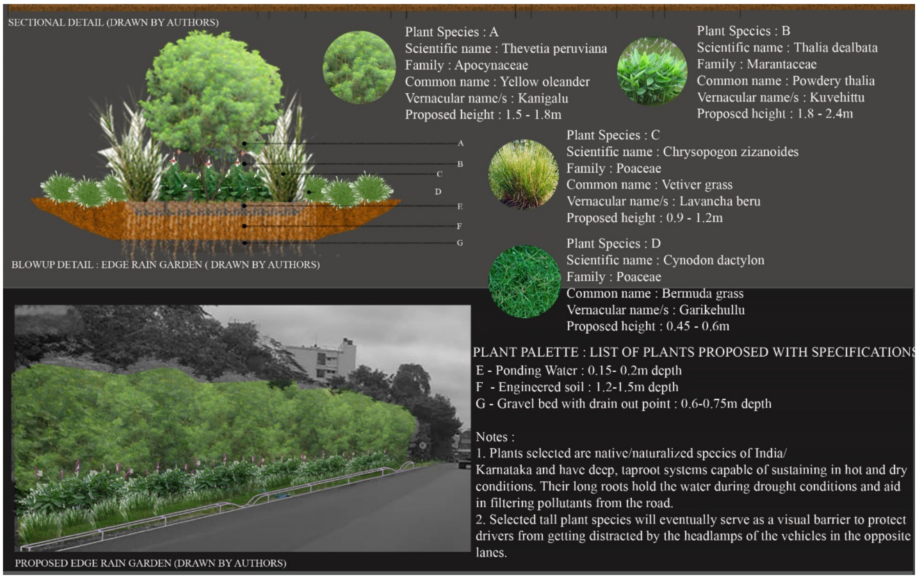


Figure 12. Model 01: Edge Rain Garden. Area of the proposed Edge Rain Garden (Both sides): Approx 339073 sqm (0.33 sqkm)

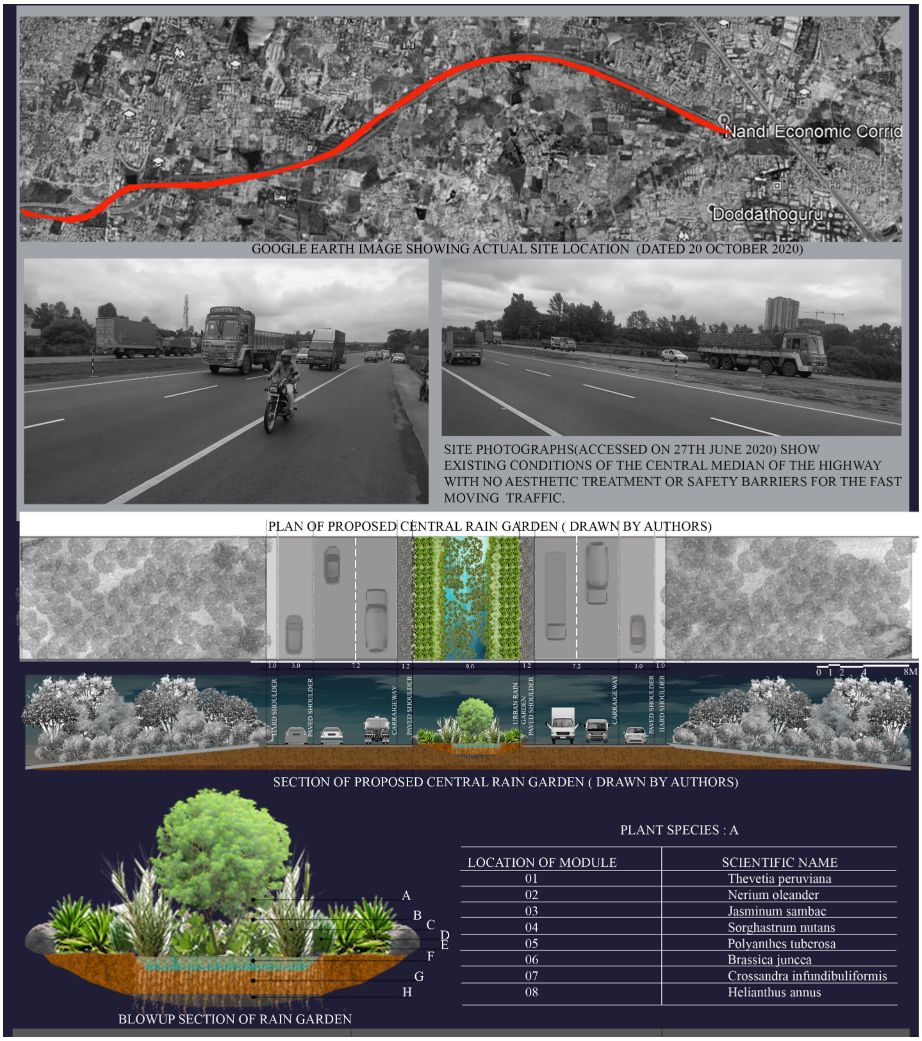


Figure 13. *To be continued*

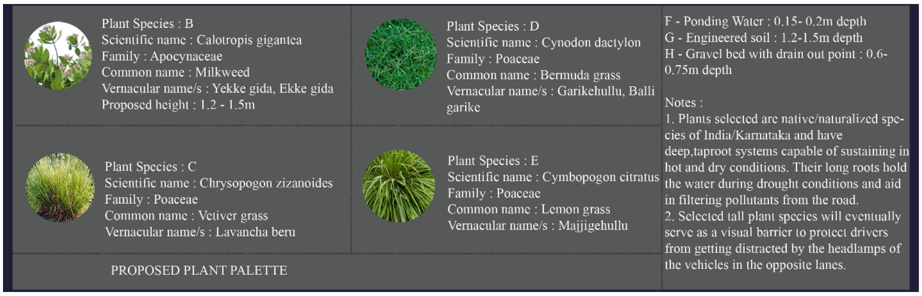


Figure 13. Model 02: Median Rain Garden. Area of the proposed Median Rain Garden: Approx 90,310 sqm (0.09 sqkm)

Scenario 2: The medians running for the entire lengths of the highway are sometimes patchy with lush planting up to a particular distance and bare lands beyond. Safety measures are not found contiguous. These have led the Model 02: Median Rain Garden (Figure 13) to be envisaged for needs of function, safety and aesthetics.

Scenario 3: Any highway/tolled roads running into miles would have points of egress taking the user into the nearby towns or cities further. This transitional space can usually be found in intersections when the user has many choices to pick from based on their point of destination. These can be designed and maintained well but can also at times become a "No man's Land", when internal government departments pass the buck from one to another pertaining to its upkeep. Uncared for and unmaintained, these spaces eventually turn into wasted pieces of land with growing wild vegetation leading to illegal activities, animal grazing and accidents. These points are taken care in the proposal of the Model 03: Intersection Rain Garden (Figure 16).

Table 3. List of "Marker Plants"

Module number	Plant species: A – "Marker Plants" Each of this species is proposed in the given module number				
	Scientific name	Family	Common name	Vernacular/ native name	proposed height (m)
01	Thevetia peruviana	Apocynaceae	Yellow oleander	Kanigalu	1.5–1.8
02	Nerium oleander	Apocynaceae	Pink oleander	Kanagale	1.5–1.8
03	Ipomoea carnea	Convolvulaceae	Pink Morning Glory	Thutu kada	1.2–1.5
04	Phragmites karka	Poaceae	Tall reed	Hulugila hullu	1.0–1.8
05	Ocimum tenuiflorum	Lamiaceae	Holy basil	Tulasi	1.2–1.5
06	Brassica juncea	Brassicaceae	Mustard	Sasuve/ Karisasive	1.0–1.2
07	Crossandra infundibuliformis	Acanthaceae	Firecracker flower	Kanakaambara	1.2–1.5
08	Helianthus annuus	Asteraceae	Common sunflower	Suryakaanti	1.5–1.8

3.3. Typical module in study area (1 km c/c) for "marker plants"

The typical module spans a running length of 1 km in the study area. The study area of 8.21 kms is divided into 7 equal divisions of 1 km each and the last module of 1.21 kms. The identified species from Table 3 is proposed in the central portion of the Median Rain garden. The remaining abutting species do not have any changes. The "Marker Plants" are proposed only in the Median Rain Garden primarily to hold the attention span of the driver. Each of the Marker plant proposed in Table 3 is highlighted with a proposed view of itself in the Rain Garden area and a typical real picture of itself in Figures 14 and 15 respectively.

3.4. Flexibility in engineering and design

Large-scale projects require long-lasting predictive solutions in terms of their feasibility, monetary gains, maintenance and associated costs all together ultimately being in demand. With technology getting outdated by the minute, a project seen with a short-term perspective would be economically and physically risky. When large projects require to be conceived, a multitude of people ranging from engineers, subject experts, technicians to statisticians, project managers, specialists and site teams are roped into the project design, development and execution. But any project however well studied and thought of cannot predict all possible outcomes that might crop up after a few decades (Neufville & Scholtes, 2011). Economic, political and social man-made conditions integrated with natural circumstances throw up a variety of best to worse case scenarios preparing the teams for the same. While it may be impossible to predict the future, the possibility of bringing in flexibility into the engineering and design components from the initial decision-making stages can provide robust long-term solutions that can be adaptable and its designers use the know-how to organize the same. Understanding flexibility in design can be seen in the simplest of our everyday lives like in the design of a car (Neufville

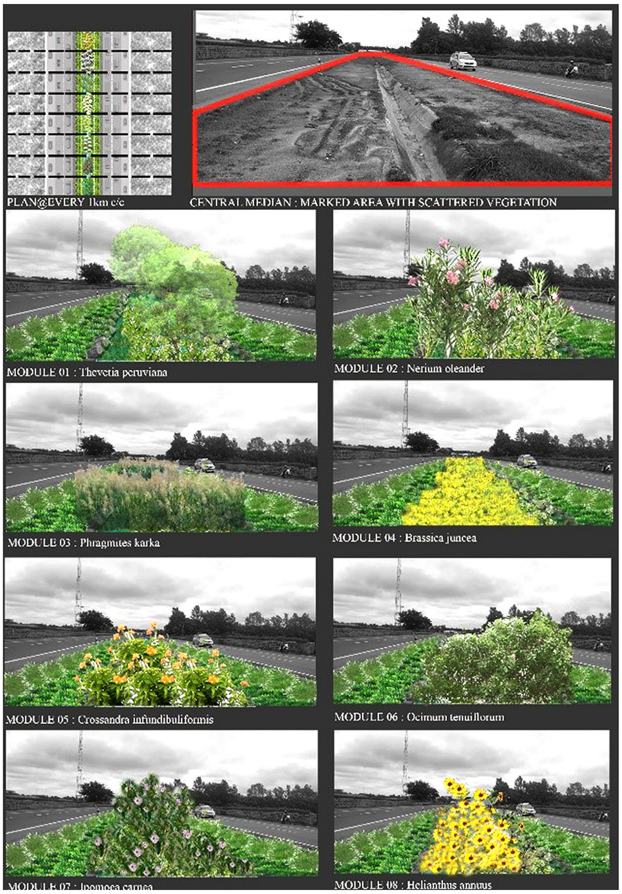


Figure 14. Proposed “Marker Plants” when planted in site

Figure 15. Proposed “Marker Plants”

& Scholtes, 2011). A car when purchased today comes with the availability of a spare tire in case one has a flat or provision of airbags in case one meets with an accident or the possibility of folding the last row seats to accommodate more baggage. This flexibility in design tries to encompass all possible aspects of safety, independence and comfort to its end user albeit with an additional price. While it might not require to use the given flexible opportunities day to day, the knowledge of having and not using it is better than not having and suddenly facing the requirement to use it.

Here in the context of efficient urban water management projects in terms of its economics, conventional methods for analysing the complex issues pertaining to forecasting and modelling to bring out the best fit optimal design for the project with the usage of basic analytic approaches like Discounted Cash Flow (DCF) Analysis or the statistical analysis has been tried and tested (Deng et al., 2013). But the drawback of such methods is the factor of uncertainty with random variables in real life situations that need to be roped in. When such variables are not considered from the initial stages, the designed model will only show the prediction as it is wanted to be perceived and would fail to perform in reality leading designers and policy-makers to make incorrect decisions fatal in the long run (Neufville & Scholtes, 2011). This is primarily because the average value of a project cannot be estimated based on the average conditions in the project. Market fluctuations, changing technology and managements with a varying demand and supply in line with varying freight and communication costs would all pile up as uncertainties that need to be considered as the project progresses. This concept known as the “Flaw of Averages” plays a crucial role in fixing the project estimate (Neufville & Scholtes, 2011). When not considered many a firm have seen projects fail, lose clients and even face insolvency leading ultimately to bankruptcy and closure (In large-scale urban water management projects, studies have shown that flexibility in design can bring performance improvements of more than 10% when compared to standard design approaches in aspects of expenditure or meeting the uncertainties like fluctuating rainfall or technical inefficiency thereby becoming vital to the decision-making process (Deng et al., 2013). In recent times across the world in almost all the cities, the framework of an urban water management project has got itself linked with flood risk management. Floods occurring in cities naturally owing to climate change and adaptation has in recent times led decision-makers to face deep uncertainties encouraging the scientists to come up with path-breaking solutions to resolve them

(Bloemen et al., 2018). A few emerging explanations with respect to climate adaptation are the use of Adaptation Pathways Approach and the Adaptation Tipping Point approach that can be worked as efficient decision strategies considering a large spectrum of scenarios possible with their outcomes and measures to solve or mitigate their effects (Manocha & Babovic, 2018) Bloemen et al., 2018. Although no approach can ever be designed for the future as an infallible method, these methods can be considered based on a broad conceptualization. The possible predicament a designer and in turn a policy-maker ultimately face is the flowchart of actions that need to be immediately implemented, the ones to be delayed in the short-term and the ones to be incorporated only in long-term. These complexities in the analysis can be approached with sequencing approaches for sub selection of pathways (Manocha & Babovic, 2018). This is all done in order to keep plans as compatible as possible for the future considering minimal losses and risks.

The above-mentioned content and solutions of flood risk management and climate adaptation can be implemented in this project in Bengaluru with similarly oriented scenarios in other urban cities of the world that have a wide and extensive scope to be explored by engineers and decision-makers associated with water management. The study area of a few kilometres, being part of a project of more than 100 km running length, is envisaged with few possible engineering solutions that can allow the future designers, engineers along with policy and decision-makers to amend according to their project's need

Figure 16. Model 03: Intersection Rain Garden. Area of the proposed Intersection Rain Gardens (Both): Approx 828 sqm (0.00083 sqkm)

Type-I-Model

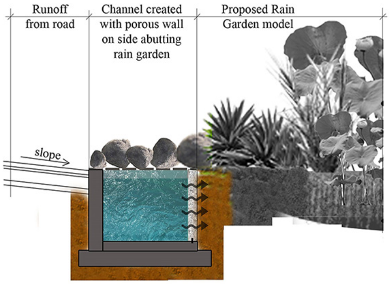


Figure 17. Model Type-I-1: Channel created to hold water built with porous wall on one side to allow water penetration into the ground at a slower pace (Jeff, 2018; Dash & Kar, 2018; Najm et al., 2017)

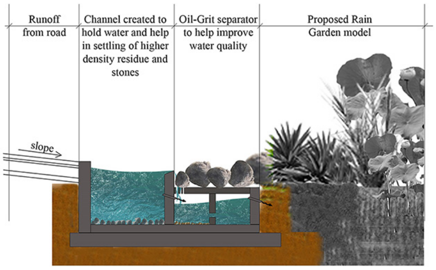


Figure 18. Model Type-I-2: Channel created to hold water attached with an oil-grit separator to filter and improve water quality before entering the rain garden (Malus, 2005; Smith, 2002)

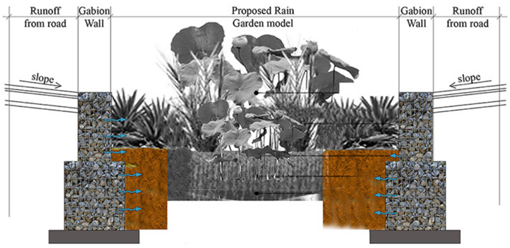


Figure 19. Model Type-I-3: Gabion walls built abutting rain garden to allow water penetration into the ground. Gabion walls act like a kerb from the safety point of view for the users and also aid as an aesthetic component (Aird, 2017; Toprak et al., 2016)

in terms of cost, material availability, maintenance and design requirement. In this paper, based on the models proposed in the methodology, three types of solutions are presented in Table 4 for the treatment of urban runoff before it reaches the proposed rain garden. The intent of doing this is to reduce the possible speed of the runoff especially in heavy rain spells and thereby avoid backflows from the rain garden along with filtering the pollutants to a certain extent. Runoff mismanaged will prove hazardous to the road users during heavy rains.

4. Recommendations

On analysing the current conditions at the exit points of the NICE Corridor at both Bannerghatta Road and Electronic City, the existence of large unkempt areas of land

Table 4. Types of solutions proposed to treat urban runoff before reaching Rain garden

S. No	Type	Basis of intent	Figure/s to be referred
1.	I	Design and Engineering	**Type I-1** : Figure 17 **Type I-2** : Figure 18 **Type I-3** : Figure 19
2.	II	Materials	Figure 20
3.	III	Technology and Automation	Figure 21

Type-II-Model

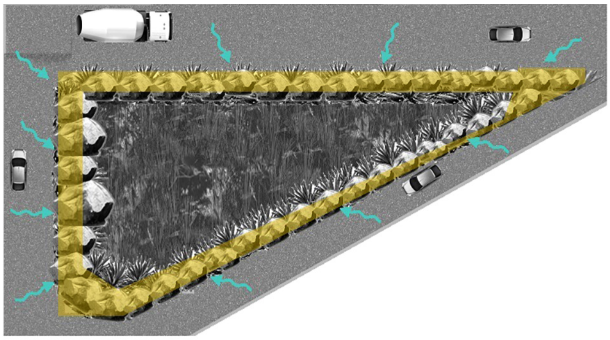


Figure 20. Model Type-II: Highlighted area in colour represents the use of porous materials like ultra-porous concrete, water permeable tiles (ex: Rainaway tiles) or porous materials strengthened with waste carbon fibre to create a composite material (Dekker, n.d.; Jeff, 2018; Najm et al., 2017)

Type-III-Model

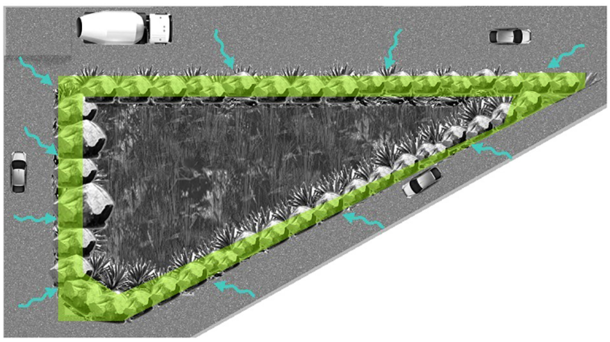


Figure 21. Model Type-III: Highlighted area in colour represents a green lawn strip. Based on automation and technology like the Sub-Air systems, these lawn strips can quickly help drain out water in times of heavy rains to avid the backflow from rain (SubAir, n.d.; Karnataka State Cricket Association, 2017)

pocket with lakes abutting them can be proposed with a model of Bioretention systems as seen in Figures 22 and 23. These systems, a counterpart of the Rain Gardens, will behave in a similar way in treating the stormwater runoff and removing the heavy metals and other pollutants washed off the roads, when designed and installed properly. Sustainable Drainage Systems (SuDS) (Priari, 2018) like Filter strips, Filter trenches and Green roads integrated with these systems and planted with native vegetation, functionally will improve the biodiversity of the lake and

Figure 22. Possibility of bioretention system with abutting Chikkathoguru Lake

Figure 23. Large, untreated land area suitable for bioretention

its precincts and aesthetically invoke a visual interest for the user.

Conclusions

The study has brought out the possibilities of benefits of using rain gardens in various scenarios in the study area. The ideal installation of the same functionally would aid the improvement of the ground water table, rejuvenate the abutting lakes and improve the biodiversity at the micro-level with native plant species attracting birds and insects. The biodiversity thus getting enhanced would induce a cyclic reaction in improving the visual aesthetics of the entire drive. The planning and implementation of a well-designed rain garden system in the study area could be the start of a typical model for any similar expressway or highway in any country.

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