Hybrid Blue-Green Infrastructure: Feasibility Study for the State of Maharashtra; India

Satpute Rushikesh[1], Khare Kanchan[2*]

[1]Symbiosis Institute of Technology (SIT), Symbiosis International (Deemed University) (SIU), Pune, Maharashtra, India, 412115

[2] Kanchan Khare, Civil Engineering Department, Symbiosis Institute of Technology, Pune, India, 412115.

*Corresponding author: kanchan.khare@sitpune.edu.in

doi: https://doi.org/10.21467/proceedings.112.20

ABSTRACT

In India, the 2019 monsoon season arrived very late and heavy, following a severe heatwave. This year's monsoons have brought the highest amount of rain in 25 years and with unprecedented spatial variability. In some districts of Maharashtra, higher-than-average rainfall caused massive flooding, which resulted in the submergence of 2 lakh hectares. Whereas remaining states saw the continued drought conditions from monsoon 2018. This unusual monsoon behaviour is considered an example of the impact of climate change and is expected to intensify and worsen over time. The combination of drought followed by heavy rainfall increases the risk of massive flooding, influence on natural and man-made systems, including infrastructure and agricultural production in flooded and dry regions. Blue-Green Infrastructure (BGI) is an interconnected network of natural and anthropogenic components, including water bodies and green and open spaces, like bio-retention cells, rain barrels, infiltration trenches, and vegetation swales. BGI has been already deployed at small scales in urban areas worldwide like in Australia and many projects are underway on larger scales in regional areas. The present study focuses on the feasibility of BGI techniques for a village Hivre Bazar, in Maharashtra. The survey of Hivre Bazar reveals that Hybrid BGI is already being practised. Hybrid BGI is a techno-social solution suitable to the culture and ancient practices in Maharashtra. If integrated Hybrid BGI is scientifically planned and implemented, it will lead to more effective solutions.

Keywords: Blue-Green Infrastructure, Feasibility study, Flooding, Hybrid BGI, Hivre Bazar.

1 Introduction

Today, floods and droughts are a typical element and their conjunction represents a robust threat, which can't be eliminated but has to be managed. Floods and droughts are periodic phenomena in India. Often, due to varying rainfall distribution and different climatic conditions in different regions, it has been observed that some parts are suffering from extreme floods. However, at the same time, another part is suffering a long drought. The same situation arises recently in Maharashtra, India in 2019. Some districts of Maharashtra like Satara, Kolhapur, Sangli, etc. received higher-than-average rainfall (heaviest monsoon in the last 25 years) caused extensive flooding, a result of this was submergence of 2 lakh hectares. To help these flood-prone regions, the government of Maharashtra releases 6800 cores for the rehabilitation of flood-affected people. On the other hand, districts like Latur, Nanded, Beed, etc (Marathwada region) saw the continued severe drought conditions. To overcome this situation, the government release 4714 cores for drought-prone regions. The condition is so worst that the government has to transport water through trains named 'The Water Express' to the drought-prone areas. The above-given situation is frequently likely to happen in the coming years because, rise in average temperatures results in warmer air which has a high capacity of holding water vapour, which

Proceedings DOI: 10.21467/proceedings.112; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-3-3

results in long dry weather and heavy precipitation in a short time. This infrequent monsoon behaviour is nothing but climate change and it is expected to boost and get worse over time. The combination of extreme rainfall events after drought raises the threat of flooding. Which not only impacts the man-made system but also nature.

If we accept climate change and plan accordingly its impact can be reduced, else there might be more serious consequences. The future will depend on today's response to climate change(Z. Ghofrani, Sposito, & Faggian, 2016). The situation will intensify due to extreme weather events. The government of Maharashtra has implemented many structural measures in Maharashtra for flood mitigation such as dykes, dams, levees, floodwalls, high flow diversions, channel alterations, spillways, stormwater management facilities, etc. However, these measures were not considered at large scale to mitigate extreme flood events(State Disaster Management Authority Mantralaya, 2016). Recently, non-structural measures like land planning, awareness generation, emergency planning, etc are developed. But these measures are not a long-term solution to the problem. There is one solution to both the problems-increase water storage, both groundwater and surface water. Structures that store water underground which helps in flood mitigation by reducing runoff and drought mitigation by providing water storage(Pavelic et al., 2015).

In response to climate change, there is a need for an anthropogenic alteration of the environment and the development of sustainable engineering solutions such as BGI. BGI increases resilience for future climate change with other co-benefits like, improve human health, economic and social welfare and improve environmental quality(Middelmann, 2007). The Blue-Green Infrastructure (BGI) approach tries to mitigate flooding and improve water quality by applying decentralized blue-green elements. These elements manage stormwater through processes of infiltration, retention, detention, evapotranspiration, and slow transport. They provide multiple benefits as conservation of local water resources, support biodiversity, mitigate climate change impacts, improve liability, socio-cultural benefits (aesthetics of urban landscape, recreation, playful urban space), other ecological benefits, and improved economic performance(Liu, Fryd, & Zhang, 2019).

To decrease the impacts of flooding in an urban area, many developed countries like Australia, Japan, the USA, etc. adopted and implemented BGI. BGI has the strength to lower the flood risk by stormwater management. Which provides cost-effective and multi-functional solutions to flooding(Zahra Ghofrani, Sposito, & Faggian, 2019; Robert, 2015) New York City and Singapore are planning a combined BGI with a conventional sewer system to reduce sewer overflows. Rotterdam is executing a variety of BGI measures to become climate-proof. Philadelphia is implementing BGI for a sustainable future. In recently, Washington develops BGI measures to improve the healthy environment in the city by reducing stormwater runoff for climate resilience(Brears, 2018).

BGI is not limited to flood reduction, but it also increases the natural capital value of that region. BGI can maximize the multifunctionality of natural capita and enhance multiple aspects of regional sustainability(Zahra Ghofrani, Sposito, & Faggian, 2020). BGI is not restricted to urban places, but its development can be considered at multiple levels like regional, peri-urban, urban, and rural(Z. Ghofrani et al., 2016). There are several success stories mainly in Urban and peri-urban regions of these developed nations. The case studies mainly focus on flash flood mitigation. A few case studies are addressing peri-urban issues and only four case studies for rural sectors.

Unfortunately, in developing countries like India, the lack of BGI awareness among the residents and policymakers is one of the major barriers to the implementation of BGI. We are therefore deprived of easily available BGI options that can be applied in one's home(Drosou et al., 2019). Many other factors like funding, socio-economic, socio-demographic status, and political background play an important role in the adoption of BGI. But we have very inspiring case studies like Hirave Bazar, Maharashtra. The residents in Hivre Bazaar have done sustainable groundwater management and implemented artificial recharge of groundwater under visionary leadership.

2 Concept of Blue-Green Infrastructure

BGI comprises natural as well as man-made systems. Which will improve environmental services with water resources management. BGI is an organized network of natural and man-made components, with green spaces and water bodies, which provide many benefits like (i)flood control, (ii)water storage, (iii) wetland areas for water purification or wildlife habitat, etc(Z. Ghofrani et al., 2016).

2.1 Components of Blue-Green Infrastructure

BGI can be classified into natural water features and man-made features, each of which includes several individual BGI components. Natural water features contain stormwater retention or detention systems, wetlands, restored waterways, and riparian buffers, each of which delivers many benefits. Stormwater detention and retention basins mainly consist of rain gardens, bio-retention basins, vegetated and bio-retention swales, etc. to reduce, store and infiltrate stormwater runoff. Riparian buffers hold a substantial volume of water, helping infiltration and release it over a longer period. Constructed wetland typically built to avoid damage to man-made structures from excess stormwater(Brears, 2018).

Man-made water features contain green roofs, blue roofs, rain barrels, green streets, infiltration trenches, gravel trenches, underground detention tanks, etc. Green roofs, and blue roofs are detention systems for capturing and holding stormwater runoff. On the other side rain barrel and underground detention, systems are used to arrest runoff and decrease peak flows. Green streets and infiltration trenches are used to increase evapotranspiration and infiltration for groundwater recharge(Brears, 2018).

2.2 Prerequisites of Blue-Green Infrastructure

The feasibility of BGI mainly depends on three parts, Practical feasibility, site feasibility, and integrated approach. The practical feasibility mainly consists of ecological features and geomorphologic conditions of regions. Whereas site feasibility uses collected data from the geological and geographical survey. Geographical data (such as land use land cover, slope, soil pollution, and ownership) is required to identify the flow of the water and to locate potential surface water storage sites. Geological data (characteristics of subsurface structures like fractures, faults, and aquifers) is the most necessary data to analyze the site for BGI implementation. In an integrated approach, we can consider multiple ecosystem parameters. Connectivity is basic for getting multiple benefits. Storage and infiltration components can be connected by linear water transition elements. In this condition, components help each other. In the way, if the full capacity of one comes, another component can be in action and collect the water. In integrated evaluation, the total scores of the BGI are calculated in terms of site feasibility and practical feasibility(Z. Ghofrani et al., 2016; Zahra Ghofrani, Faggian, & Sposito, 2017)

2.3 Data collection and post-processing of the data

The information required for such an investigation includes demographic, geological, morphological data, ecological data, and other data as per the case study requirements. This data is both explicit (survey data) and tacit (working knowledge and perceptions of planning professionals). In the second place, data collection by accessing interview partners and informational material, which means working with several local researchers who share diverse backgrounds and experiences.

The collected data is then applied to planning support systems (PSS) like BeST, Adaptation support tool (AST), etc(Ashley et al., 2018). The tools help to choose several practicable alternative adaptation components of BGI among many others. The total scores of blue-green measures on-site feasibility and practical feasibility were calculated to assess their supplemental to the existing conditions. After that other benefits of combining BGI measures such as storage and harvesting measures, attenuation measures, infiltration measures, cooling measures, etc. are used to formulate an adaptation package. Depending on the scale of the project, three to four highest-ranking measures are included in the adaptation package(Zahra Ghofrani et al., 2019; Voskamp & Van de Ven, 2015)

As soon as the adaptation package is selected, which contains three to four BGI measures, the performance of the adaptation package is evaluated using different modeling tools like Urban Stormwater Improvement Conceptualisation (MUSIC), PCSWMM, Info work, etc(Zahra Ghofrani et al., 2019, 2020) They are capable of integrating and modeling different types of BGI components. These models also calculate the life-cycle cost of each BGI component. Modeling results give efficiency of each BGI component or combination of BGI components towards adaptation measures such as storage and harvesting measures, attenuation measures, infiltration measures, cooling measures, etc, or towards extreme events like floods and droughts. Some GIS-based modeling tools give the location of each BGI component in the study area based on geological and geographical data.

After analyzing the performance of each BGI component or combination of BGI components, implementation of the same is the next step. Each BGI component is implemented on-site with the help of GIS-based modeling results.

3 Study area

Hivre Bazar village is situated in the Ahmednagar district of Maharashtra State, India (Latitude 19.093 and Longitude 74.620). It is located around 17 km west of Ahmednagar. Hivre bazaar is bounded by hills on three sides. The main village is situated at the lowermost of the hills, towards the south. The total population of Hivre bazaar is around 1,140 and these are divided amongst 226 families. The total geographical area of the village is about 976 ha.

Agriculture is the major occupation of the village. Both cash crops and food crops are grown in the village. Principal crops in Hivre bazaar include bajra, jawar, rice, wheat, onions, turmeric, sugarcane, cotton, and several oil seeds.

Hivre bazaar experienced acute water scarcity and serious land degradation during 1970. The traditional water management system failed in that duration. In 1972-1980 because of long-term drought with constant crop failure and resulted in 50% people migration. In 1990, only 12% of the land was under cultivation.

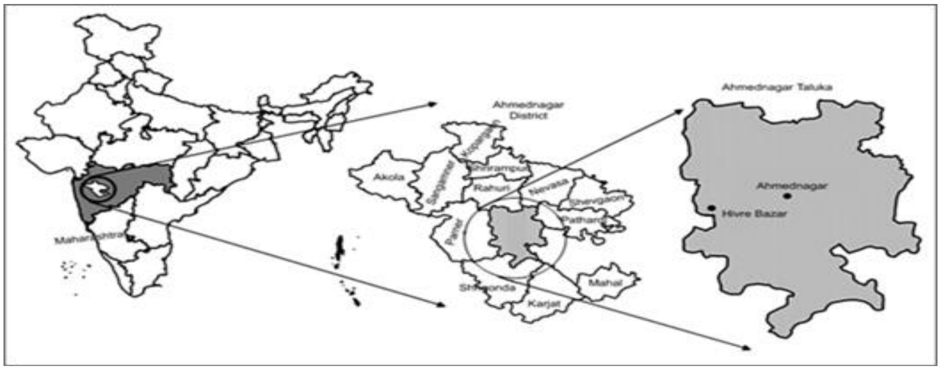

Figure 1. location map of Hivre bazar(Menon, Singh, & Shah, 2007)

4 Feasibility of Blue-Green Infrastructure for Hivre bazar

BGI can exist at several geographic levels such as rural, urban, catchment, city-region, site, etc. It works across administrative boundaries. Hence, BGI isn't limited to urban places, but its development can be considered at several levels like peri-urban, regional, and rural(Zahra Ghofrani, Sposito, & Faggian, 2017).

BGI is very site-specific because it depends on site characteristics, land uses, and hydrological conditions. Maharashtra is a part of the Deccan trap. Deccan trap contains a massive accumulation of volcanic rocks, mainly basaltic lavas which covers 90% of Maharashtra's geological area. Basalt has a low hydraulic conductivity of 1-2 m/d, which makes it difficult for groundwater storage and recharge. So, regions like Maharashtra required blue-green infrastructure components with the integration of artificial recharge structures to get maximum benefits. The feasibility of Blue-green Infrastructure mainly depends on three parts, Practical feasibility, site feasibility, and integrated approach.

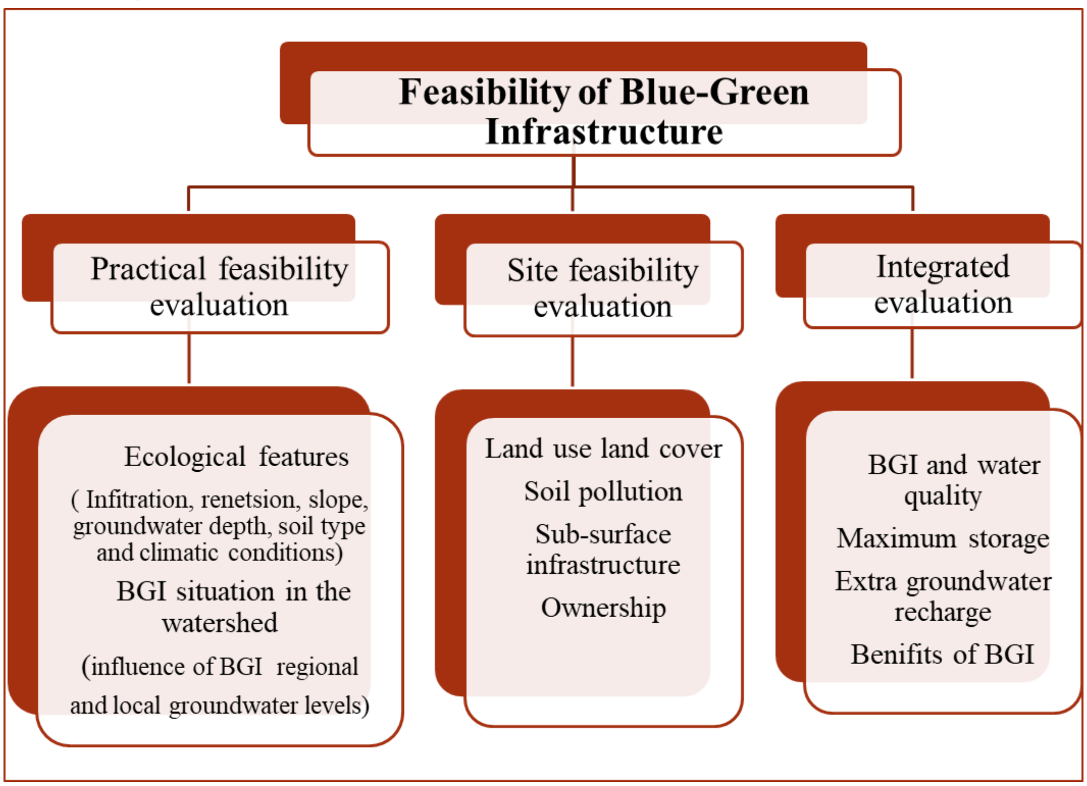

Figure 2. Feasibility of Blue-green infrastructure

Proceedings DOI: 10.21467/proceedings.112

Series: AIJR Proceedings
ISBN: 978-81-947843-3-3
ISSN: 2582-3922

4.1 Site feasibility

Hivre bazaar is bounded by hills on three sides. The main village is situated at the bottom of hills, towards the south. Hence Hiware bazaar lies in high sloping areas. Hills are the part of Deccan trap. Deccan trap contains a massive accumulation of volcanic rocks, mainly basaltic (Basalt) lavas. Basalt has a low hydraulic conductivity of 1-2 m/d, which makes it difficult for groundwater storage and recharge. To overcome this, 103 borewells were drilled (diameter 150 mm and a depth ranging from 5 to 18 m) in 1620 sq. m. of the land area using Bore Well Blast Technique (BBT) in 2006 to create artificial fractures and cracks in hard basalt rock for artificial recharge(Artificial Recharge to Ground Water in Hivre Bazar, 2007).

For soil conservation, Hivre bazar implemented many structures like continuous contour trenches around hill slopes, plantation, compartment bunding, terracing, graded bunds, vegetative contour bunds, etc. to avoid soil erosion and harvest water. Around 70 ha land is afforested. The Number of water conservation structures like percolation tanks, check dams, brushwood dams, loose boulder earthen structures, underground bandharas, diversion bunds, nullahs bunds, cement nullah bunds, farm ponds, etc. were built in the village through many government fundings. The total no of soil and water conservation structures is listed in table 1.

Table1. Soil and water conservation structures at Hivre Bazar
(Artificial Recharge to Ground Water in Hivre Bazar, 2007)

Type of work		Area/Numbers
Contour Bunding		414 Ha.
Afforestation		70 Ha.
Continuous contour trenches (CCT)		10 Ha.
Deep C C T		0.36 Ha
Plantation on Bunds		206 Ha
Loose Boulders		120 Nos.
NallaBunding		29 Nos.
Percolation Tank		02 Nos.
Storage Bandhara		05 Nos.
Cement Nall bunds		4 Nos.

4.2 Practical feasibility

Hivre bazaar is divided into three sub-watersheds. The largest is on the southern and western sides. The second sub-watershed drains the hills of the western side and the third one is on the eastern side(Menon et al., 2007). Agricultural land on the southern side (upper reach) contains hill topsoil mainly consist of pebbles and gravels wash down from the hilltop. Whereas on the northern side (lower reach), better quality soil (better water holding capacity) is found. Groundwater availability in lower reaches is higher than in other parts of the village. The best quality of soil lies in the middle portion. Which mainly consist of phupata, Gohadbastis, and padir(Menon et al., 2007). Out of the total geographical area, 81% that is 795 ha is under cultivation.

Hivre bazar has a typical monsoon climate. It has three seasons (monsoon, winter, and summer) in the year. Tropical conditions dominate all over the state. In the summer season (march-may) temperature varying from

22°C-39°C. on the other side in winter (October-February) temperature falls to 12°C-34°C. In the rainy season (June-September), Hivre bazaar receives only 300-400 mm average annual rainfall.

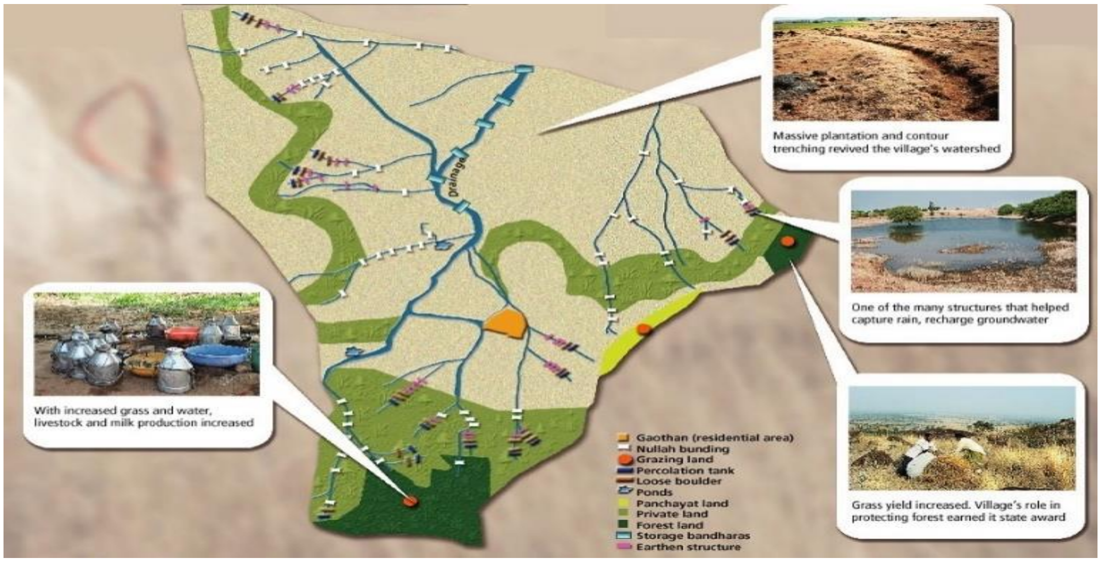

Figure 3- location of water conservation structures in Hivre bazaar till 2007
(Indian water portal, 2007)

5 Hybrid Blue-Green Infrastructure created at Hivre Bazar

The village is trapped in a rain-shadow area and receives less than 15 inches of rainfall every year. To overcome the water need, leadership along with public participation initiated rainwater harvesting schemes. They introduced the watershed conservation and management program in the village. With state government funds, they established several water bodies, including 52 earthen bunds, 32 stone bunds, check dams, and percolation tanks to store rainwater, as well as *lakhs* (thousands) of trees were planted (Table no-1)

The watershed technique helped farmers to harvest different crops. With just 90 wells back in 1990, this tiny village now has around 294 water wells. In a span of just a few years, the water level began to rise in the wells and other man-made structures around the village, thus farming was back in full swing and became the main source of income for the villagers. The village abandoned the use of water-intensive crops, and instead, vegetables, pulses, fruit, and flowers that use less water were grown.

Recently, Hivre Bazaar is earning a cost-effective harvest of water management. With an increase in water availability grass production also increases. It results in higher milk production, from 150 liter to 2200 liter for each day from the 1990s to 2019. During 2006, agricultural earnings were approximately Rs 1652/month per capita which is almost twice (Rs 890/month) India's top-earning rural population. According to the household survey 1992, only 3 families under the poverty line. Every village which faces the problem of water scarcity and poverty should learn from the success story of Hivre bazaar, that integrated water resource management and local participation can solve the problems faced by villages.

6 Conclusion

The case study of Hivare Bazaar is people participatory attempt of implementation of hybrid Blue-Green Infrastructure. The residents of having good knowledge of local geography and geology and even challenges to be faced. Primary stakeholders role is very significant in the implementation of BGI. Hivare Bazaar therefore has transformed from a water-scarce area to a water surplus area.

Proceedings DOI: 10.21467/proceedings.112 Series: AIJR Proceedings
ISBN: 978-81-947843-3-3 ISSN: 2582-3922

The efforts in this direction can be more lasting if an integrated and scientific approach is adopted.

From the case study of Hiware bazaar, it is concluded that Hybrid BGI is feasible and can be adopted in the Indian context. Its effectivity would enhance if modern tools and techniques are used. There are many success stories of BGI from developed countries but many developing countries like India are facing various challenges, such as socio-economic, political, and cultural barriers, lack of awareness about planning, design, and implementation of BGI. There is an urgent need to create awareness about the concept and its advantages among the policymakers, stakeholders, and end-users.

Hybrid BGI is a techno-social solution suitable to the culture and ancient practices in Maharashtra. If hybrid BGI is scientifically planned, adopted, and implemented with an original blending of very rich ancient cultural practices along with modern techniques it will lead to more effective solutions.

How to Cite this Article:

Rushikesh, S., & Kanchan, K. (2021). Hybrid Blue-Green Infrastructure: Feasibility Study for the State of Maharashtra; India. *AIJR Proceedings*, 162-169.

References

Artificial Recharge to Ground Water in Hivre Bazar. , (2007).

Ashley, R., Gersonius, B., Digman, C., Horton, B., Smith, B., & Shaffer, P. (2018). Including uncertainty in valuing blue and green infrastructure for stormwater management. *Ecosystem Services*, *33*(November 2017), 237–246. https://doi.org/10.1016/j.ecoser.2018.08.011

Brears, R. C. (2018). Blue and green cities: The role of blue-green infrastructure in managing urban water resources. In *Blue and Green Cities: The Role of Blue-Green Infrastructure in Managing Urban Water Resources*. https://doi.org/10.1057/978-1-137-59258-3

Drosou, N., Soetanto, R., Hermawan, F., Chmutina, K., Bosher, L., & Hatmoko, J. U. D. (2019). Key factors influencing wider adoption of blue-green infrastructure in developing cities. *Water (Switzerland)*, *11*(6). https://doi.org/10.3390/w11061234

Ghofrani, Z., Sposito, V., & Faggian, R. (2016). Designing resilient regions by applying Blue-Green Infrastructure concepts. *The Sustainable City XI*, *1*(Sc), 493–505. https://doi.org/10.2495/sc160421

Ghofrani, Zahra, Faggian, R., & Sposito, V. (2017). A comprehensive review of blue-green infrastructure. In *International Journal of Environment and Sustainability* (Vol. 6).

Ghofrani, Zahra, Sposito, V., & Faggian, R. (2017). A Comprehensive Review of Blue-Green Infrastructure Concepts. *International Journal of Environment and Sustainability*, *6*(1). https://doi.org/10.24102/ijes.v6i1.728

Ghofrani, Zahra, Sposito, V., & Faggian, R. (2019). Modelling the impacts of blue-green infrastructure on rainfall runoff: A case study of Eastern Victoria, Australia. *International Journal of Water*, *13*(2), 151–172. https://doi.org/10.1504/IJW.2019.099514

Ghofrani, Zahra, Sposito, V., & Faggian, R. (2020). *Maximising the Value of Natural Capital in a Changing Climate Through the Integration of Blue-Green Infrastructure*. 213–234.

Indian water portal. *Water balance sheet - Hivre Bazar*. , (2007).

Liu, L., Fryd, O., & Zhang, S. (2019). Blue-green infrastructure for sustainable urban stormwater management-lessons from six municipality-led pilot projects in Beijing and Copenhagen. *Water (Switzerland)*, *11*(10), 1–16. https://doi.org/10.3390/w11102024

Menon, A., Singh, P., & Shah. (2007). *Community-Based Natural Resource Management: Issues and Cases from South Asia*. https://doi.org/10.4135/9788132101550

Middelmann, M. H. (2007). *Natural Hazards in Australia: Identifying Risk Analysis Requirements*. Risk and Impact Analysis Group Geospatial and Earth Monitoring Division Geoscience Australia.

Pavelic, P., Karthikeyan, B., Amarnath, G., Eriyagama, N., Muthuwatta, L., Smakhtin, V., … Kant, L. (2015). Controlling floods and droughts through underground storage: From concept to pilot implementation in the ganges river basin. In *IWMI Research Report* (Vol. 165). https://doi.org/10.5337/2016.200

Robert, S. (2015). *From vision to reality: making cities flood resilient by implementing green infrastructure strategies*. UNESCO-IHE Institute for Water Education, Delft, the Netherlands.

State Disaster Management Authority Mantralaya, M. (2016). *Maharashtra State Disaster Management Plan*. https://doi.org/10.1017/CBO9781107415324.004

Voskamp, I. M., & Van de Ven, F. H. M. (2015). Planning support system for climate adaptation: Composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events. *Building and Environment*, *83*, 159–167. https://doi.org/10.1016/j.buildenv.2014.07.018