Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726), 10(X), 2022: http://dx.doi.org/

Review on sponge city construction for flood management.

Revisión de la construcción de la ciudad esponja para la gestión de inundaciones.

Femin Maria IX, Elba Helen George

Department of Civil Engineering, Toc H Institute of Science and Technology, Ernakulam (Kerala), India

Corresponding author mail id: feminmariaix@gmail.com, elbaheleng@tistcochin.edu.in

ABSTRACT

Due to the global climate change and the rapid progress of urbanization, the frequent occurrence of flooding disasters and severe pollution seriously threaten the sustainable development of modern cities. To solve these problems, China first started the construction of the 'Sponge City'. Sponge city can improve city's ability to adapt to the environment change and to cope with floods; it can also make them more sustainable. It was not only meant for urban flood control, but also rainwater harvest, ecological restoration of urban land and water quality improvement. The rainfall received in 2020 in Hyderabad of India, has been the highest for the month October in a century. The risk is going to increase year after year in the whole nation. So India too needs a mission that mitigates flood risk and provides a pathway to water security. And the most promising solution across the world at this time can be the idea to adopt Sponge city construction. Improper research in this field will lead to huge maintenance difficulties and other related problems. This paper mainly focuses on presenting the concepts of sponge city construction along with its pathway. Not only does it focus on Sponge city's benefits, but also its challenges are also stated, which leads to better understanding about its scope of continuing for future.

Keywords: Flood control, sponge city, green infrastructure, urban floods.

RESUMEN

Debido al cambio climático global y al rápido progreso de la urbanización, la ocurrencia frecuente de desastres por inundaciones y la contaminación severa amenazan seriamente el desarrollo sostenible de las ciudades modernas. Para resolver estos problemas, China inició primero la construcción de la "Ciudad Esponja". Sponge City puede mejorar la capacidad de la ciudad para adaptarse al cambio ambiental y hacer frente a las inundaciones; también puede

hacerlos más sostenibles. No solo estaba destinado al control de inundaciones urbanas, sino también a la recolección de agua de lluvia, la restauración ecológica de la tierra urbana y la mejora de la calidad del agua. La precipitación recibida en 2020 en Hyderabad de India, ha sido la más alta para el mes de octubre en un siglo. El riesgo aumentará año tras año en toda la nación. Por tanto, la India también necesita una misión que mitigue el riesgo de inundaciones y proporcione un camino hacia la seguridad hídrica. Y la solución más prometedora en todo el mundo en este momento puede ser la idea de adoptar la construcción de Sponge City. Una investigación inadecuada en este campo conducirá a enormes dificultades de mantenimiento y otros problemas relacionados. Este artículo se centra principalmente en presentar los conceptos de la construcción de la ciudad esponja junto con su camino. No solo se enfoca en los beneficios de Sponge City, sino que también se enuncian sus desafíos, lo que conduce a una mejor comprensión de su alcance para continuar en el futuro.

Palabras clave: control de inundaciones, ciudad esponja, infraestructura verde, inundaciones urbanas.

INTRODUCTION

Flood is the most common and costliest natural disaster in the world which ruins both life and economy at a huge extent. In recent years, urbanization, high-intensity human activities and the population growth at rapid phase, lead to extremely serious environmental problems all over the whole world. Among those problems, the impact of urban storm water runoff on the urban environment was a serious issue. (Dingkun Yin et al. 2020) The combined action of rainfall, the degree of urbanization, and the low capacity of drainage systems results in extreme urban flooding disasters. Under the background of global climate change and urbanization development, the improvement in urban rainfall management.

The Sponge city has the same function as a sponge, which can effectively adapt to environmental changes and handle natural disasters. (Jinjun Zhou et al. 2018) Fig 1 shows the schematic representation of sponge city. Water can be absorbed in the event of heavy rainfall, and when necessary, the stored water can be released in time of drought. Therefore, Sponge City projects can contribute to controlling floods and can effectively collect rainwater for future use, thereby satisfying the requirements of green infrastructure and sustainable development. (Lin Zhang et al. 2019)

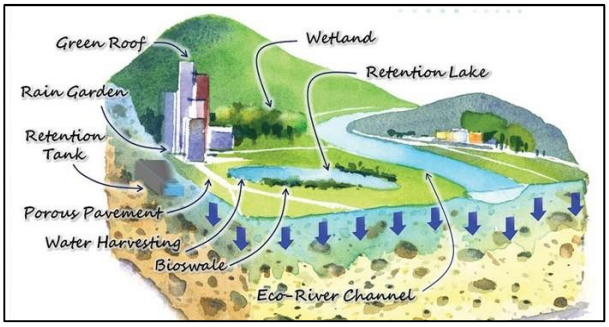

Fig 1: sponge city schematic diagram

PRINCIPLE CONCEPT

There are four main principle concepts involved in the Sponge City. The first is to make the surface of the city better to absorb and store rainwater in order to supply water and to mitigate the stormwater runoff. The second principle is about water ecology management via water self-purification systems and the provision of ecological waterfront design. The third is concerned with the application of green infrastructure to purify, restore, adjust and reuse stormwater. (Thu Thuy Nguyen et al. 2019) Fourthly, using permeable pavements in urban road construction.

Resourcing rainwater: Rainwater harvesting includes the collection and storage of rainwater from rooftops and also other building surfaces for domestic purposes and for use at the time of drought. (Bao-Jie He et al. 2019) The existing rainwater harvesting actually focused only on restoring and recycling of stormwater without focusing on its other benefits. In order to resource rainwater successfully, it is necessary to understand the area's hydrological characteristics including water surface runoff, discharge, speed, flow time, size and peak time. This helps in improving the connection between natural water networks and urban drainage systems, thus to control urban flooding. (Chris Zevenbergen et al. 2018) For rainwater harvesting, ductile iron pipe system can also be used, which includes a pipe trench with the ductile iron pipes. This acts as a storage space for rainwater beneath the road. Water reaching non-polluted surfaces such as roof surfaces can be directly

discharged into this storage space. Polluted rainwater is first pre-treated and then discharged into the rainwater storage system.

Ecological water management: The Sponge City concept makes sure that the water environment is restored ecologically with the help of a self-purification system and waterfront design. The creation of healthy water landscapes is also a part of ecological water management. The self- purification of water is significantly influenced by many factors, which include the soil, the plants, the microorganisms and the physical, biological chemical process of flowing water. Another mode of ecological water management is through ecological waterfront design. (Yong Jiang et al. 2018) In the construction of a Sponge City, both natural and artificial ecological waterfronts will help in protecting against erosion from riverbanks.

Green infrastructure: Green infrastructure has been developed as the solution to protect the environment and make urban environments sustainable. The implementation of Sponge City involves green infrastructures with nature-based solutions such as detention basins, filter drains, infiltration systems, filter steeps, wetlands and swales. (Yongjun Sun et al. 2020) Mainly there are two types of green infrastructure in Sponge City implementation: green roofs and bio-retention.

Green roofs: Green roofs are also known as living roofs or rooftop Gardens. In its construction, Green roofs are made by covering it with vegetation or plants. They have many benefits like; they help in mitigating the urban heat island effect, reducing storm water runoff, enhancing quality of air and water, reducing energy consumption and improving wildlife habitat and plant life. Green roofs consist of five main layers of components, ie; a waterproof membrane, a layer of drainage system, a filter membrane, soil and plants. (Zhang Yu-shu, 2017) For green roof design, it should be properly covered with soil; 40-60 cm thick layer is appropriate for planting small trees;40 cm for shrubs;30 cm for ground covers and vines; and 20 cm for lawns. (X J Pan, 2019)

Bio-retention: Bio-retention systems are also popularly known as bio-filters or rain gardens. Normally, a bio-retention system consists of five components, they are; drainage layer, transition layer, submerged zone, filter media and detention layer. These help in filtering the polluted storm water and removing the included contaminants through biological processes using active live plants and sandy loam layers. Bio-retention systems are considered as one of the most feasible solutions in sustainable rainwater management practices. These systems, as small sponges for cities, have been a popular method to control urban flooding.

Rain gardens and bioswales: Building rain gardens and bioswales is good way to make cities hold water. A rain garden is a depression in the soil seeded with native plants that helps absorb rainwater. With this kind of setup, house spouts can be emptied into a rain garden instead of a sewer, decreasing sewage overflows in heavy downpours. A bioswale is a rain garden on a larger, more engineered scale. In this, water can be temporarily accumulated and this water can also be drained out slowly.

Urban permeable pavement: Permeable pavement is a Sponge City technology that utilizes permeable materials to build ground pavement. The permeable pavement helps to improve rainwater infiltration, purification of groundwater for urban supply, reducing water runoff, cooling, humidification, noise reduction, environmental and ecological soil restoration. Urban pavement includes roads, parking lots, squares and urban site walkways. As the key material for the construction of sponge cities, the pervious concrete has great potential to solve flooding problems with its continuous voids through gap grading the aggregate and eliminating the usage of fine aggregate which will allow the water and air to pass from the surface to underground easily. (Weiguo Shen, 2020)

PATH OF SPONGE CITY CONSTRUCTION

Being a systematic project, sponge city construction has the following procedures: First, the city's original ecosystem has to be protected. While undergoing urban construction activities and its development procedures, the protection of the original rivers, lakes, wetlands, ponds, ditches and other natural areas have to be taken care and their protection have to be maximized and their maintenance activities also have to be ensured.

Second, ecological restoration and repair work have to done periodically. For damaged waters and other natural environments, ecological means have to be used for its recovery and repair works. A certain proportion of ecological space have to be always maintained and water ecological infrastructure should also be built.

Third, the concept of low impact development has to be implemented. The intensity of urban development has to be controlled reasonably and should minimize the destruction of the original urban water ecological environment. According to the needs, rivers, lakes, and ditches have to be properly excavated, the water area has to be increased, the accumulation of rainwater, infiltration and purification have to be promoted and the size and quality of the urban "sponge" have to be thus improved.

Fourth, the utilization and management of urban rain and flood resources have to be strengthened considerably. The surface runoff generated by urban precipitation have to be managed by proper means. Permeable spaces have to be provided for easy infilteration and

proper drainage facilities have to be ensured. Under the premise of ensuring safety, a flood disaster risk management system as well as personal hedging and disaster prevention and mitigation for buildings and other adaptive measures have to be established. (Shuhan Zhang et al. 2018).

BENEFITS OF SPONGE CITIES

By using sponge city measures, rainwater can be absorbed naturally, and can even be captured and repurposed for irrigation, home use and other needs during the time of drought. China, by adopting sponge city practices, plans for 80 percent of its urban cities to harvest and reuse 70 percent of rainwater. This innovative idea can be adopted by other countries too. (D. Su et al. 2019) Following the philosophy of innovation, a sponge city can solve water scarcity problems instead of creating them. Instead of funnelling away the rainwater, sponge city retains it for use within its own boundaries. It's a resource to augment our water supply. In the long run, sponge cities will reduce carbon emissions and help fight climate change. The reduction in the amount of stone and concrete used in urban infrastructure, leads to an automatic reduction in the amount of cement CO_2 emissions incurred. (Jinjun Zhou et al. 2018) Cement accounts for roughly 8 percent of all man-made greenhouse gas emissions, and any reduction is welcome. If properly implemented, a sponge city can reduce the frequency and severity of floods and improve water quality. By capturing stormwater, it helps in preventing beach pollution. Associated strategies such as green space can improve quality of life, improve air quality and reduce urban heat islands. Cities tend to be hotter than the surrounding area. Through their incorporation of natural features, sponge city designs help to reduce this excess heat. Tree-planting is a highly effective method of improving a city's microclimate. Water can be used to keep green spaces verdant, provide an outdoor area for the people who live and work in the building, and even be used to grow food. This in turn can improve urban ecosystem diversity by providing new habitats for a wider range of organisms. Grass swales, artificial ponds, wetlands and rain gardens all add to the visual appeal and calming effect of urban development. Sponge cities also gives an aesthetic beauty to cities with the incorporation of Grass swales, wetlands, artificial ponds and rain gardens, which adds a visual appeal (Linyuan Leng et al. 2020)

CHALLENGES IN SPONGE CITIES

At present, as the concept of sponge city is gaining popularity, the technologies adopted on its construction are widely studied and accepted by government all around the world. But there are numerous challenges in its implementation and upscaling. There are challenges like technical, physical, financial, Legal and Regulatory Challenges, Public Acceptance Challenges and also interagency or data sharing challenges. Considering technical challenges, the improper research foundation will restrict the positive effect of the project at large extent

unnecessarily. Also considering the current practices, there exhibits

a pattern of using one similar model for every part of the country which can't be acceptable as the local conditions would differ for different areas. Therefore, sponge city strategies should be developed based on proper research of local conditions and its potentials. The lack of knowledge and guidance and lack of design standards and codes, as well as insufficient education and training in its concepts may result in the poor planning and implementation which will lead to other huge maintenance problems in future. Also, sponge city measures require more frequent and periodic maintenance. There are also some maintenance challenges ie; some of sponge city measures are located on private property as well, making it difficult for public agencies to ensure whether proper maintenance is carried out or not. Physical Challenges include, some sponge city measures may not be suitable and can't be adopted in certain locations due to the physical characteristics of the land, climate, or other conditions. The traditional systems in urban areas convey stormwater through underground pipes, whereas in sponge city practice, stormwater is infiltrated into the ground or maybe stored on-site. This requires additional land. Financial Challenges are also a big factor. In current practices, funding for initial construction will be allocated but funding needed for future operation and maintenance are not addressed properly. Also due to the uncertainty of the life-span of this project, the life-cycle benefits including environmental, ecological and social benefits cannot be assessed in an appropriate manner. As there is no clear picture of the future benefits, the financial risk for both public and private entities will be higher. (Zongmin Li et al. 2018) Considering Legal and Regulatory Challenges, building codes; plumbing and health codes; restrictions involving street width, drainage codes, and parking spaces; and restrictions on the use of reclaimed stormwater are all a challenging factor. Public Acceptance Challenges include Public opinion and the denial of their interest can also easily hinder its success. There are also Inter-Agency Cooperation and Data Sharing Challenges ie, Lack of inter-agency cooperation also leads to difficulties in data and information sharing. It hinders research and innovations. In some situations, repetitive efforts were directed to collect the same data or information which will be time consuming. (Hui Li et al. 2017)

WHERE DOES INDIA STAND?

Many cities in India such as Chennai, Delhi, Bangalore, etc are going to run out of groundwater by 2020-21, according to NITI Aayog report. Over the past decade, India has seen many huge floods at various places such as Hyderabad (2020), Maharashtra (2019), Kerala (2018), Mumbai (2017), Chennai (2015), Kashmir (2014) and many more. India is get bruised both ways- lack of water & excess of flood. Incorporating the Sponge City idea under the area of smart city project would save countless lives and leads to the implementation of sustainable cities. The expense for making this into reality may cost some money, but the benefits these projects will provide are enormous. Nowadays across the globe, countries are coping up with the climate change by adopting innovative and

sustainable water conservation measures. NITI Aayog, in its Composite Water Management Index Report, stated in detail about the water crisis in our country. As per the report, India is suffering from terrible water crisis in its history and around 600 million Indians face water stress in many forms. Many cities like Bengaluru, Delhi, Hyderabad and Chennai are going to face groundwater scarcity by the middle of 2021. In contrast, it is also very clear that many of these towns and cities undergo huge problems of urban flooding every year due to intense rainfall. We need to channelize this excess rainfall into a water storage system so that situation of water crisis can be dealt with and at the same time, by doing so, flooding can be controlled. The existing infrastructure is to be renovated on the blueprint of a sponge city to accommodate the consequences of extreme level of rainfalls and surface runoffs. Sponge City design thus would act as a defense mechanism, during rainstorms, supporting greater absorption and water retention. Thus, it leads as a pathway for of sustainable Indian cities.

CASE STUDY OF HYDERABAD FLOODS

City of Hyderabad in India with a population of around 1 crore (2020) and spread over an area of 55sq.km, had faced many severe floods over the past decade. Also, the latest victim of urban flooding in India is Hyderabad. The city as well Telangana received unusually excessive rainfall October 13-14, 2020, due to a deep depression that developed in the Bay of Bengal. Heavy damage to property, roads and human lives has been reported. Cities are growing in size as well as population. The natural path of water from elevated areas to lower ground is being blocked by new offices, markets, colonies, etc. The rainwater gets diverted to other routes and follows the roads and lanes of other parts of city.

Long term and short-term sponge city measures have to be taken to mitigate these floods. In the short term, the natural path of water drainage from high altitude to a lower one, should be traced and its pathway have to be cleared. These routes have been blocked or encroached due to rapid urbanization. In the long term, an underground drainage system should be constructed to flush rainwater from any place. A proper drainage system have to be constructed and this excess water that cause flooding, instead of discharging it into Musi river in Hyderabad, they have to be collected and stored for future use. Roads and parking lots have to be constructed with permeable pavements, thereby the over flooded situation of roads can be solved to an extent. Greener infrastructure has to be included. It is proven that by increasing green space areas by 10%, the runoff peak maybe slowed down by 20 min. In Hyderabad, the city receives close to 828.5mm of annual rainfall, thus rainwater harvesting (RWH) is one of the best solutions to its water issues. Rainwater harvesting structures must be constructed wherever possible especially in localities of Ameerpet, Khairatabad, Trimulgherry, Marredpally and Musheerabad, which are

facing huge water stress. Thus, following sponge city construction is the best way to deal with water issues in Hyderabad.

CONCLUSION

High rainfall is not the only reason for urban flooding. The combined action of rainfall, the urbanization, and the low capacity of drainage systems and also the high intensity human activities result in an urban flooding disaster. As the global climate change and urban development is leading to huge problems, improvement of urban rainfall and flood management should be paid serious attention. Nowadays, many cities are going back to what they were before urban development, to resolve the negative impacts of urbanization. If done correctly, bringing in more nature or buildings around existing green space will solve many of the problems. A sponge city could reduce urban water logging, but won't be able to eradicate fully, and the effect of sponge city construction depends on its infiltration and storage capacity. For countries which are developing at a rapid pace, especially developing countries like India, the sponge concept needs to be urgently implemented even though there are monetary problems. The porous pavements and natural solutions together can be embraced to solve flooding problems. In Bangalore, urban wetlands as well as woodlands are in process of restoration. Likewise, the sponge city solutions should be implemented in India in wide basis to conserve water and put an end to urban flooding. The sponge city construction can play a positive influence on the management of urban water resources, urban flood control, ecological construction, and land use.

REFERENCES

He, B-J., Zhu, J., Zhao, D-X., Gou, Z-H., Qi, J-D., Wang, J., (2019) Co-benefits approach: Opportunities for implementing sponge city and urban heat island mitigation, Land Use Policy 86. 148-149.

Jiang, Y., Zevenbergen, C., and Ma, Y., (2018), Urban pluvial flooding and stormwater management: A contemporary review of China's challenges and "sponge cities" strategy. Environmental Science and Policy 80, 132-135.

Leng, L., Mao, X., Jia, H., Xu, T., Chen, A.S., Yin, D., and Fu, G., (2020), Performance assessment of coupled green-grey-blue systems for Sponge City construction. Science of the Total Environment 728, 12-13.

Li, H., Ding, L., Ren, M., Li, C., and Wang, H., (2017), Sponge City Construction in China: A Survey of the Challenges and Opportunities, pp.6-12.

Li, Z., Xu, S., and Yao, L., (2018), A Systematic Literature Mining of Sponge City: Trends, Foci and Challenges Standing Ahead, 2-14

Nguyen, T.T., Ngo, H.H., Guo, W., Wang, X.C., Ren, N., Li, G., Ding, J., and Liang, H., (2019),

Implementation of a specific urban water management - Sponge City. Science of the Total Environment 652, 148-159.

Pan, X.J., (2019), Coupling of urban green space system and sponge city construction. IOP Conference Series: Earth and Environmental Science, 9-11.

Shen, W., Liu, Y., Wu, M., Zhang, D., Du, X., Zhao, D., Xu, G., Zhang, B., and Xiong, X., (2020), Ecological carbonated steel slag pervious concrete prepared as a key material of sponge city. Journal of Cleaner Production 256, 2-3.

Su, D., Zhang, Q.H., Ngo, H.H., Dzakpasu, M., Guo, W.S., and Wang, W.S. (2019), Development of a water cycle management approach to Sponge City construction in Xi'an, China. Science of the Total Environment 685, 493-494

Sun, Y., Deng, L., Pan, S-Y., Chiang, P-C., Sable, S.S., and Shah, K.J., (2020), Integration of green and gray infrastructures for sponge city: Water and energy nexus. Water-Energy Nexus 3, 30-35

Yin, D., Chen, Y., Jia, H., Wang, Q., Chen, Z., Xu, C., Li, Q., Wang, W., Yang, Y., Fu, G., S. Chen, A., (2020), Sponge city practice in China: A review of construction, assessment, operational and maintenance. Journal of Cleaner Production, 2-3

Zevenbergen, C., Fu D., and Pathirana, A., (2018), Transitioning to Sponge Cities: Challenges and Opportunities to Address Urban Water Problems in China, 1-4

Zhang, L., Sun, X., and Xue, H., (2019), Identifying critical risks in Sponge City PPP projects using DEMATEL method: A case study of China. Journal of Cleaner Production 226, 950-953.

Zhang, Y-S., (2017), Sponge City Theory and its Application in Landscape. World Construction, 6(1), 31-33.

Zhang, S., Li, Y., Ma, M., Song, T., and Song, R., (2018), Storm Water Management and Flood Control in Sponge City Construction of Beijing, 1-6

Zhou, J., Liu, J., Shao, W., Yu, Y., Zhang, K., Wang Y., and Mei, C., (2018), Effective Evaluation of Infiltration and Storage Measures in Sponge City Construction: A Case Study of Fenghuang City, 1-2.

Received: 15th February 2021; Accepted: 04th May 2021; First distributed: 04th May 2021