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# Sustainable Urban Drainage System (SUDS) as Nature Based Solutions Approach for Flood Risk Management in High-Density Urban Settlement

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# Sustainable Urban Drainage System (SUDS) as Nature Based Solutions Approach for Flood Risk Management in High-Density Urban Settlement

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**Abstract.** Nature-based Solution (NBS) is an umbrella for ecosystem-based approaches to prevent or mitigate the impacts of hydro-meteorological hazards. The increasing hydro-meteorological disaster occurrence such as floods in Bandung City because of both climate change phenomenon and rapid growth of Bandung City has caused a big impact on people live in slums and high-density settlement. Realizing this risk, Bandung City has implemented strategies to reduce flood risk, including the Sustainable Urban Drainage System (SUDS) as stated on the Bandung City Spatial Plan (RTRW) 2011-2031. However, this measure had not effectively reduced flood risk in Bandung City. Therefore, this research focuses to analyse the implementation of SUDS and how it can capture the concept of NBS, with the study case Cibadak Administrative Village, one of the poor and high-density urban settlements in Bandung City. The result was developed using a mixed method consisting of a descriptive quantitative approach, spatial analysis for satellite imagery, and content analysis technique to analyse each challenge of SUDS implementation. The result indicates the lack of capacity in scale, budget, natural characteristic, and social demographic for SUDS implementation in poor and high-density urban settlement in Bandung, which aligns with the challenge of NBS implementation in the global south.

## 1. Introduction

Over half of the Indonesian population now is living in urban area. The number will be increasing to 67.1% in 2045 based on the BPS projection [1]. Rapid urban population growth brings a number of challenges, such as lack of basic infrastructures, traffic jams[2], environmental problems, such as water and/or air pollution [3,4]. This is also happening with the loss of urban natural spaces in pursuit of space for built up areas [5]. In addition, the population growth will increase a lot of problems and lead to disasters in urban areas [6]. Besides that, disasters in Indonesia have been increased rapidly from 2000-2010, and hydro-meteorological disasters induced by climate change such as flood account for more than 70% of the disasters in Indonesia [7]. Inadequately managed and planned rapid growth in urban area will create threats that undermine existing development accomplishments. Besides that, uncontrollable rapid growth area can cause poverty, resulting to have no access to clean drinking water, no sewage system and can lead to water scarcity, especially in the dry season [8]. Moreover, poor urban management can also increase vulnerability and risk of flooding [9].

Bandung City as the fourth dense city in Indonesia with a population of 2.5 million [10], meanwhile, population in Bandung Metropolitan Area is 8,790,308 [11] and it has faced similar problems with the urban population, including the provision of settlement and basic needs. Based on BNPB data (2021), almost 90% of Bandung City area is highly prone to flooding, mostly in the southern part of the city. In 2020, floods in Bandung City have inundated 25 locations, most of which are high-density settlements. Floods in Bandung City often occur because of climate change and land-use conversion, thus leading to water catchment areas shrinkage, affecting the increase of infiltration level in the area, and creating a high flow of run-off water [12,13]. Furthermore, the inadequacy of drainage channels to drain excessive run-off water causes floods. This significantly affects the community's risk of hydro-meteorological hazards in poor and high-density settlements.

Cibadak Administrative Village is located in the centre of Bandung City with an area of 0.473 $km^2$ and 13,370 population [10]. Cibadak is also crossed by the Citepus River, which is the stream of the Citarum River. Water from the river always overflowed during the rainy season and caused flooding in that area that made several houses inundated. Besides that, there have been many lands use changes into built-up areas in Cibadak, causing a reduction in infiltration areas. Moreover, there have been several programmes from the Bandung City Government to mitigate the flood which is mainly focused on structural conventional measures such as building water embankment. However, the effectiveness of this measure is still questionable since some hamlets are still often flooded. Realizing this challenge, flood risk reduction innovations are needed that take into account the hydrological system and physical characteristics of the settlement and prioritize the ecosystem. Meanwhile, Bandung City has implemented strategies to reduce flood risk, including the Sustainable Urban Drainage System (SUDS) based on the Bandung RTRW 2011-2031. However, this measure had not effectively reduced flood risk in Bandung City.

NBS is an umbrella for ecosystem-based approaches to prevent or mitigate the impacts of hydro-meteorological hazards. NBS brings more sustainability and addressing societal challenges as well as providing human well-being and biodiversity benefits. SUDS as a promising NBS type have various benefits ranging from flood risk management to water management [14]. Based on the prior research, the research about SUDS still focused on discussing the types of SUDS that are suitable to be applied in urban areas [15], identifying SUDS performance and the factors that influence it [16], as well as the importance of SUDS in stormwater management [17]. Therefore, this research aims to fill the research gap by analysing the challenge implementing SUDS in high-density settlement and slum area and how it can capture the concept of NBS, with the study case of Cibadak, one of the poor and high-density urban settlements in Bandung City.

## 2. Literature Review

### *2.1. Hydro-meteorological Hazard and High-Density Settlement*

Globally, hydrometeorological disasters reckon for more than 75% of damage, including loss of life, economic loss, infrastructure damage, and regular life disruption [18]. The UNISDR [19] defines a *hydrometeorological hazard* as a phenomena that can damage infrastructure, environmental aspects, economic losses, and social disturbances. Of all hydrometeorological disasters, floods are one of the most frequent and expensive hydrometeorological disasters [20]. From the estimation, the average population per year affected by floods is expected to rise from 1 million in 1990 to 25 million in 2050 due to global warming climate change [21]. Floods strike all countries and prompt further destructiveness and goods and property harm than some different kind of hazard. Floods can disturb water purifying and residue disposal systems and produce toxic water waste sited to overflow, primarily in high-density settlements.

Settlements with high density are easy to identify through satellite imagery because of the proximity of residential buildings [22]. High-density urban settlements refer to areas located in urban areas. Housing is the primary land use, with a building area of less than 90 per cent. According to European Commission, high-density settlements are designated as all cells including the local community density of at slightest 1,500 residents/$km^2$ or with a locally built area division of about 0.50 and clustered in 4 connectivity objects of at least 50,000 people or all cells following from median filtering of 3x3 or with gap-filling <15 $km^2$ (median filtering and gap-filling are referred to a group of cells that provide the prior logic).

In most countries, high-density settlements are amongst the most defenceless to flood. The natural characteristics and high-density settlements risk scale change because of the dynamic land-use patterns, unplanned growth, and climate change impacts. In addition, the floods impact increment on high-density settlements is because of the area of residences in the floodplain area, the construction of dams that join the rivers across which transportation routes overlap, the decline in current drainage into ineffective hydro-technical products, and more.

With widespread urbanisation and high-density settlements, the potential for damage to human life and infrastructure is enormous. Vulnerability of flood includes parts at the chance, such as the inhabitants of a flood-prone area, a built environment, or an ecosystem revealed to flood hazard [23]. Meantime, vulnerability remains commonly recognised by many researchers to consist of three components: degree of exposure, susceptivity and resilience or response capacity of a population in a remarkable area [24].

### *2.2. Sustainable Urban Drainage System (SUDS) in High Density Settlement*

Urbanisation phenomenon has led to the impermeabilization of the soil, causing a greater volume of surface runoff. When it converged to lower regions, the greater volume of runoff becomes one of the main causes of flooding [25]. The efficiency of traditional drainage in managing the increasing amount of surface runoff have significantly decreased because they have designed according to a determined return period and how many users that use them. Therefore, the SUDS was introduced as it includes different technologies and techniques in a more sustainable manner [26]. SUDS is an approach to decelerate and decrease surface water runoff which aims to reduce downstream flood risk and possibilities of pollution caused by the runoff. It includes reaping, penetrating, decelerating, reserving, transporting and handling runoff on site [27].

SUDS imitates natural processes to protect water cycles from negative impacts of development [26]. The way SUDS work makes it appear as one of the most promising form of NBS implementation. SUDS tackles water quality problems and, at the same time, enhances green spaces within developments, supporting the ideal condition for habitats and places for wildlife to live and flourish [27]. For urban areas that are highly populated, these co-benefits of SUDS implementation are very much needed because urban development has replaced well-drained soil with impermeable or imprevious surfaces; hence, disturbing the water cycle in urban ecosystems [28,29]. Moreover, High-density urban areas are faced with a lot of problems regarding the quantity and quality of urban water. Hence, the SUDS implementation in high-density urban areas is crucial so that surface runoff can be well-managed.

Successful integration of SUDS into urban design will require an early consideration of surface water as part of the design and planning process, and also a collaborative and interdisciplinary team that [27]. However, implementing SUDS in urban areas can face several challenges [30]. Placing a combined SUDS components in sequences and spread around the development are can help to create an effective system (good water quality and hydraulics) that does not require too much of a cost [27]. In general. there are four factors that contribute to the implementation of SUDS, namely scale, natural characteristics, social demographic, budget, and planning (see Table 1 for more details).

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**Table 1. Factors, Variables, and Indicators that Affect the Implementation of SUDS**

| **Factor** | ***Variable*** | ***Indicator*** | ***Parameter*** | ***Source*** |
|---|---|---|---|---|
| **Scale** | Type/use of open space | Public space | The existence of parks, squares, roads dividers, sidewalks, or parking lots. | (Jiménez Ariza et al., 2019) |
| | | Private space | The existence of open space of residential, commercial, and industrial areas, or public facilities. | |
| | Spatial aspect | Land value | High/low land value due to competing development objectives. | (Kuller et al., 2017) |
| | | Land zoning | SUDS implementations require a specific drainage plan | |
| **Natural characteristics** | Soil | Type | Soil with good infiltration capacity | (Kuller et al., 2017) |
| | Slope | Slope rate | Steep slopes are prohibitive to most SUDS types | |
| | Hydrology | Topography | Natural drainage channel availability | |
| | | Proximity to water body | The closer to the water body, the easier to implement SUDS | |
| | Climate | Rainfall averages | Rainfall averages determine the volume and condition of water managed by SUDS | |
| | | Temperature | Local temperature determines plant selection, and it is important to several types of SUDS | |
| | Urban Fabric | Roof surface areas | Flat rooftop will facilitate green roof implementation | |
| | | Open space | Some SUDS technologies favour or require open space. | |
| | | Permeable pavement | Permeable pavements facilitate infiltration | |
| | Ecosystem Type | Available vegetation | Vegetation improves infiltration | |
| | Flood hazard | Depth of inundation | Inundation leads to floods and material loss | (Minister of Public Works and Public Housing, 2014) |
| | | Duration of inundation | The longer an area being drowned, the higher the losses | |
| | | Inundation area | Bigger inundation area means bigger or higher losses | |
| | | Inundation frequency | More frequent floods mean bigger losses | |
| | Flood impacts | Tangible impact | Tangible impact on public or private properties influences the type and location of SUDS | (Hammond et al., 2015) |
| | | Intangible impact | Intangible impact on health increases the community awareness | |
| **Social Demographic** | Demographic | Income | Micro approach of the SUDS is more suitable for community or area with low average income | (Kuller et al., 2017) |
| | | Density | High population density usually has higher levels of imperviousness | |
| | Public awareness and values | Risk awareness and value | Public awareness and values determine the degree of community acceptance towards SUDS | |
| | Social cohesion | Volunteering | The existence of volunteering activities indicates community initiative. | |
| | | Community organization membership | Participation in community organization enhance coordination and mutual assistance | |
| **Budget and Planning** | Political stability | Political responsiveness | SUDS requires strong, ongoing, and responsive commitment from government | (Kuller et al., 2017) |
| | Development opportunity | Organizational capacity | Opportunities for development of SUDS may arise from high organisational capacity and coordination | |
| | Economic cost | Initial cost | Initial costs are estimated to determine the SUDS type that fits the budget | (Gogate et al., 2017) |
| | | Operation and Maintenance (O&M) Cost | O&M costs per year are estimated to maintain the quality of SUDS | |

## 3. Methods

Cibadak administrative village was chosen as the location for this research because it is one of the densely populated settlements in Bandung City that is very prone to flood disaster. This research aims to identify the challenges in the implementation of SUDS in high-density settlement and how it captures the concept of Nature-based Solution.

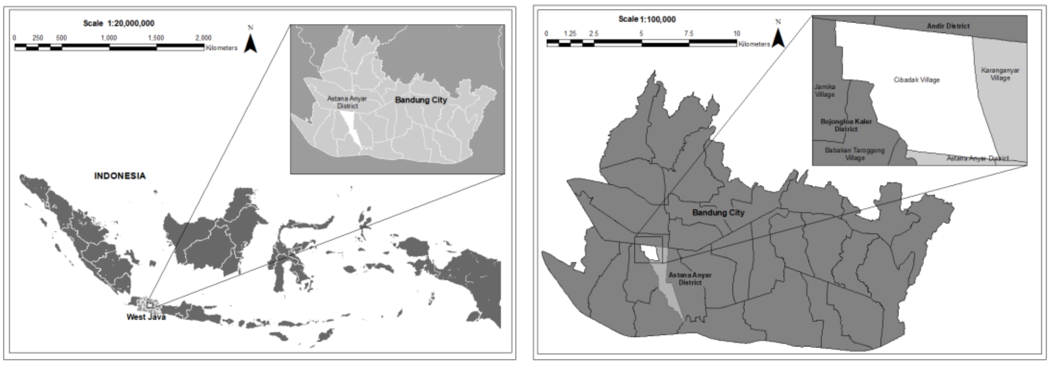


**Figure 1.** Map of Study Location

It uses mixed-method approach consisting of quantitative, qualitative, and spatial analysis. The quantitative approach is used to analyse the statistical data, including slope rate, temperature, rainfall averages, proximity to receiving water body, and flood hazards (depth of inundation, duration of inundation, inundation area, inundation frequency). Besides that, the spatial analysis is also used to describe the characteristics of the land use zone, urban fabric, availability of vegetation, and density. Meanwhile, content analysis as qualitative approach is carried out to explore the historical causes, conditions and impacts of flooding in Cibadak administrative village as well as the challenge in implementing SUDS in that area. Furthermore, Secondary data collection is conducted through literature review related to the previous SUDS research, online news about flood in Cibadak administrative village, regulation, programs, and policies about flood risk management in Bandung city or Cibadak administrative village. On the other hand, primary data collection is utilised through in-depth interview with local stakeholder and observation from worldview image and field documentation. Stakeholders for in-depth interview are selected based on purposive sampling to obtain the first key informants who have better understanding about flood condition in that area and other key informants are explored through snowball sampling from the recommendation of the first key informants.

## 4. Results and Discussions

As stated on the Bandung City Spatial Plan (RTRW) 2011-2031, Bandung City has implemented SUDS as one of the strategies to reduce flood risk although further details are needed regarding the locations and the types of SUDS implemented in the city. This study explores some challenges in implementing SUDS in high density settlement. The results will be elaborated in four sections based on the factors that contribute to the implementation of SUDS.

### *4.1. Scale of Implementation*

The first factor is scale of implementation, which refers to the site selection process of where the SUDS infrastructure will be built. The scale of implementation determined by type/use of the open space so SUDS can be built in either public open spaces, private open spaces, or both. There are several steps or procedures that should be taken to determine or design the most feasible and suitable SUDS that can be implemented [31]. In Cibadak administrative village, most of the land use area is private space, which indicates from the previous observation and the spatial analysis. 64,56% (31,06

Km$^2$) of the area is private and build up area. This makes various implementations of large-scale SUDS more difficult to implement, due to limited public land. On the other hand, micro or household scale SUDS would be an appropriate option to implement in Cibadak Administratie Village.

*"The difficulty to implement the SUDS is the availability of space. It is because the location is very dense, densely populated. Even for the previous programme to find a location to create local garden was very difficult. Then, we had another option to look for plants that can absorb water and we looked for the yard of the community's house which is wide enough to grow the plant."*
M. Dio Wana Paratama, Chief of *Karang Taruna* of Cibadak Administratie Village

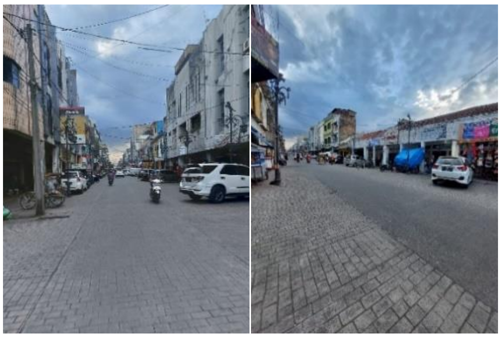

**Figure 2. Type of Build-up Area of Cibadak**

The second variable of spatial aspect refers to the land value and land zoning or regulation in the area where the SUDS will be built. In Cibadak, the land value has been increasing due to the rapid development in this area. From the interview with the local government, they stated that currently the land value in Cibadak is about IDR 13.000.000 – 25.000.000 per m$^2$. Hence, transforming the existing land use to SUDS would be a big challenge. This situation aligns with Woods Ballard et al., (2015) research that mentioned about sites within urban areas are often confined and restricted, and land is often more valuable, which means introducing SUDS will be challenging because it is faced with competing development purposes. Furthermore, land zoning refers to the classification of urban areas based on the different land uses. Based on Bandung Spatial Plan, Cibadak classified as high-density settlement, trade and services centre, and some part of river watershed. Current land use mostly has the same classification as the spatial plan. However, there is the lack of river watershed area and proper drainage system in Cibadak since there is no specific legislation or drainage plan in that area [32].

**Figure 3.** Conventional Drainage System in Cibadak administrative village (Left) and the Citepus River (Right)

*4.2. Natural Characteristics*

Natural characteristics can be observed through the site characterises and the flood conditions. Based on the Bandung RTRW 2011-2031, generally the soil type in Bandung City consists of alluvial soil and latosol soil, while in Cibadak administrative villages, most of the soil is alluvial. This type of soil is formed from dry silt deposits through water flow and gravity force, as a result, this soil is prone to erosion. Meanwhile, the slope in that area is around 0 – 15%, meaning that the slope is flat or sloping and it caused the area to be more prone to flooding. Besides that, for hydrology conditions, there is the Citepus River as a natural drainage channel that crosses Cibadak Administrative Village. This river often overflowed when it rained heavily in the north, carrying black-colored water because it was polluted with garbage from the upstream. The conditions around the river are also the factors in the occurrence of flooding because there are many settlements established in river border areas so that there is no open space to absorb stormwater runoff. Whereas, it has been regulated in Government Regulation No. 38 of 2011 concerning Rivers that the borderline of the embankment river in the urban area is at least 3 meters from the outer edge of the embankment foot along the river channel.

Furthermore, regarding climatic conditions, the average temperature in Cibadak administrative village is between 22ºC – 25ºC, while for the rainfall, the heaviest rain occurred in December at around 313.5 mm, related to severe flooding in December 2020. Meanwhile, through observing the urban fabric, it is noticeable that most of the building roofs are not flat, meaning that the implementation of green roofs as a type of SUDS is not possible. Besides that, the availability of open space is also few, only 1,28 km2 as the total area. In addition, the road pavement in Cibadak generally uses asphalt and very little vegetation so that the absorption of rainwater runoff becomes slow.

Based on the interview, floods always occur during the rainy season, especially consignment floods originating from the north. The tributaries (7 - 8 tributaries) in the Citepus river cause water to overflow faster during heavy rain.

*"As a matter of fact, the flood that happened in Cibadak was consignment flood from the north. Meawnhile, the community here actually has already been aware to throw the rubbish into the dustbin. However, there are approximatelly 7 tributaries that enter the Citepus River. Thus, it caused flood and carried black-colored water."*

Ceppy Setiawan, Chief of Hamlet 2, Cibadak Administrative Village

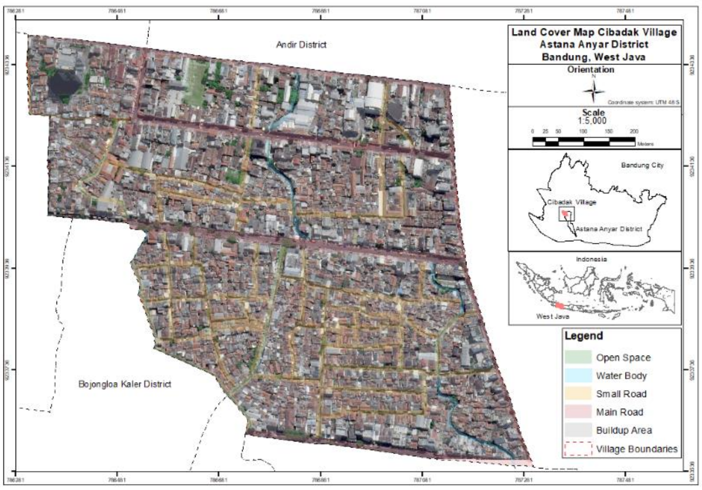


**Figure 4.** Map of Land Cover in Cibadak Administrative Village

The area is also inundated easier because of the lower soil structure conditions in Hamlet 5, 6, 7 and 8. The local stakeholder also mentioned that the average inundation depth was 1 meter, while the highest inundation which reached 2 meters occurred in December 2020. Meanwhile, in most flood cases in Cibadak, the inundation duration was around 1 – 1.5 hours, which happened almost 9 – 10 times a year. The floods inundated a large area in the administrative village, covering Hamlet 5, 6, 7, and 8 causing a huge amount of material loss. Meanwhile, a flood with a depth of 2 meters caused several residents' houses damage, bridge damage and flooded irrigation [33].

### *4.3. Social Demographic*

While other structural mitigation measures rely on government top-down projects, SUDS requires community's initiatives and responsibilities in the implementation since it is part of decentralized systems located in neighbourhood scale [34]. Moreover, challenges also found on the maintenance phase after the implementation of SUDS since the community might facing constraints to continuously engaging in the implementation of SUDS [35]. Therefore, social demographic characteristics such as demographic characteristics, public awareness and values, and social cohesion perform an essential role in the implementation and maintenance of SUDS.

From the survey, it was found that most the residents of Cibadak administrative village are traders whose income is relatively small. Riverbanks alongside the Citepus River become the place they choose as a place to live which might be an unfavourable location for higher socio-economic status groups. Furthermore, income and house price are related to the suitability of the SUDS types, where low-income groups of residents with low house prices are more feasible in implementing the micro approach of SUDS. On the other hand, population density also influences the suitability of SUDS implementation. Based on spatial analysis, it is found that Cibadak administrative villages is a high-density settlement with high population density. This kind of settlements typically related to higher levels of imperviousness.

The second variable of social demographic factor identified in this study is public awareness of the risk and their understanding about SUDS. From the interview, we found that the community is already aware with the flood that happened in their area because they have experienced it for years and they also have already known about what to do during and after the flood. Meanwhile for their understanding about SUDS, they said that they are quite familiar with SUDS, however, the implementation of SUDS is still limited in their area.

*"Yes, that's right. They are used to flooding. It's normal for them to clean up the mud after the flood."*
Ceppy Setiawan, Chief of Hamlet 2, Cibadak Administrative Village

Social cohesion, as the third variable in social demographic factor, illustrates the social capital that the community owns and uses to take care of other people and its surroundings which are impacted by the floods. The social cohesion in this community was found in volunteering activities and community organization membership such as *Karang Taruna* (youth community organization). The key informants mentioned that Fire and Disaster Management Agency in Bandung City has held a training about disaster response and recovery for the residents. Residents are also accustomed to doing *Gotong Royong* (cooperation and community service) after a flood occurs. Furthermore, the community organization membership affected how a community cooperate and take care of its surroundings.

### *4.4. Budget and Planning*

The first point in budget and planning factor is political responsiveness, which means that SUDS requires strong, ongoing, and responsive commitment from the government. In Bandung City, there are several governmental regulations that were made to strengthen disaster management efforts, including floods. In a broad sense, there are two regulations. The first one is Regulation of the Mayor of Bandung City Number 626 of 2017 concerning the Establishment of the Organization and Work Procedure of the Bandung City Disaster Management Implementing Unit, and the second one is Bandung City Regional Regulation Number 9 Year 2009 concerning Regional Medium Term Development Plan (RPJM) 2009-2013. In the RPJM document, the government outlined the guidelines for disaster mitigation strategies and plans for the classification of protected areas, such as Northern Bandung that is often hit by hazards. Furthermore, there is Bandung RTRW 2011-2031, which specifically mentioned the urgency to improve drainage infrastructure services in order to overcome the problems of flooding and inundation.

The second point is development opportunity, which can be seen from the organisational capacity in disaster management efforts. Based on the result of our interviews with Chief of Hamlet 2 of Cibadak Administrative Village and Chief of *Karang Taruna* of Cibadak Administrative Village, it can be understood that the local government of Cibadak Village is always cautious and on-guard whenever rain hits the area, and that they will know what to do if flood follows the rain and that the local government of Cibadak Village has a good coordination with the local community, the district-level government, and also the Social Office of Bandung City, to help them finding good shelters for the evacuated persons. The organisational capacity can also be seen from disaster management related trainings that have been done at Cibadak Administrative Village. Chief of Hamlet 2 of Cibadak Village stated that there was a training on how to handle flood risks held by Bandung City's Office of Fire and Disaster Management, and Chief of *Karang Taruna* of Cibadak Village stated that there is a regular training on how to handle floods, such as how to evacuate people trapped in the flooding, which safety tools should be used, how to provide public kitchen, and more. The training prepares the residents to be able to evacuate themselves during the floods, and a basic knowledge of post-disaster recovery such as collecting data on the affected houses, fatalities and material loss, and where to get help. Moreover, there are also several flood management related programs that have been implemented in Cibadak Village that involve the community

"*There was a program called Citarum Harum, also a program by BRI Peduli in which a water filter was built and then taught the community on how to build green areas to filtrate water. There was also a program that built biopore, but it was not really effective to reduce floods in Hamlet 6 and 7.*"
M. Dio Wana Paratama, Chief of *Karang Taruna* of Cibadak Administrative Village

However, for the third point (economic cost), both Chief of Hamlet 2 and Chief of *Karang Taruna* of Cibadak Village stated that they mostly relied on voluntary funding for emergency posts and public kitchen, and that they must ask to the district government or the Social Office of Bandung City first to get the funding for the recovery of the affected community and for assistance in the form of the nine basic needs. If SUDS will be built and implemented in Cibadak, the local government should prepare a stable source of funding and can no longer rely on the voluntary funding, because SUDS will need not only initial cost, but also operational and maintenance costs throughout the year to ensure it functions and works effectively.

## 5. Conclusion: Implementation Challenge of SUDS in Bandung High Density Settlement

High-density settlements, especially that located alongside the riverbank, are known for the high level of flood risk. Many conventional structural measures have been implemented to reduce the risk, but that have not yet demonstrated the best result. For urban areas that are highly populated, such as Cibadak administrative village in Bandung, an innovative solution that refers to natrue-based is needed to mitigate flooding. As stated on the Bandung RTRW 2011-2031, Bandung City has implemented Sustainable Urban Drainage System (SUDS) which is one type of Nature-based Solution for mitigating the impacts of hydro-meteorological hazards. However, this implementation faced several challenges which is explored in this paper. In general, SUDS works by mimicking natural hydrological processes which includes harvesting, infiltrating, slowing, storing, conveying, and treating runoff on site [27]. Some examples of the SUDS that can be implemented in Cibadak admistrative village are green roofs, permeable surfaces, infiltration trenches, filter drains and filter strips, swales - shallow drainage channels, detention basins and purpose-built ponds and wetlands [36]. These examples can be implemented in every different landscape, nevertheless the implementation should be considering the characteristic of each area especially for high density settlement.

Based on the four factors explored in this study, it can be concluded that the adaptability of the scale, budget, and natural characteristic of urban settlement as the challenges in implementing SUDS in high-density settlement. From the scale perspective, various implementations of large-scale SUDS are more difficult to implement, due to limited public land and high land value in Cibadak. Nevertheless, micro or household scale SUDS would be an appropriate option to implement. Meanwhile, since SUDS (especially micro and household SUDS) requires individual or community initiatives, they also facing financial constraints because they mostly relied on voluntary funding. Moreover, based on physical characteristics of Cibadak administrative village, it is found that the site conditions such as flat slope, hydrological nature of riverbanks, climate variability, settlement density, and the lack of vegetation and open spaces make SUDS even more challenging to be implemented.

On the other hand, there are also opportunities for the implementation of SUDS in Cibadak administrative village in terms of its social cohesion and the existence of government support. The residents of Cibadak administrative village are aware of the impact of flooding and are ready to help those who are affected with Gotong Royong mechanism coordinating by *Karang Taruna*. Meanwhile, in terms of planning, there are several regulations of Bandung City that can enable and support the implementation of SUDS in Cibadak administrative village. Besides that, in order to reduce community vulnerability, the city government, along with community organisations have conducted several trainings related to flood management. Furthermore, this also indicate the challenges faced in implementing SUDS was in accordance with NBS implementation as a new approach in global south, such as the biophysical environment and the climate aspect, the risks in the environment, the relationships between human and nature, the policy and governance aspect[5].

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**References**

[1] Indonesia S. Indonesia Population Projection 2015–2045. Statistics Indonesia, Jakarta 2018.
[2] Ellis P and Roberts M 2016 Leveraging Urbanization in South Asia. World Bank Group 207.
[3] Khan I and Zhao M 2019 Water resource management and public preferences for water ecosystem services: A choice experiment approach for inland river basin management. Sci Total Environ **646** 821–31. https://doi.org/10.1016/j.scitotenv.2018.07.339.
[4] Zhang S, Liu B, Zhu D, and Cheng M 2018 Explaining Individual Subjective Well-Being of Urban China Based on the Four-Capital Model. Sustainability **10** 1–14.
[5] Lechner A, Gomes R, Rodrigues L, Ashfold M, Selvam S, Wong EP, et al 2020 Challenges and considerations of applying nature-based solutions in low- and middle-income countries in Southeast and East Asia. Blue-Green Systems 2. https://doi.org/10.2166/bgs.2020.014.
[6] Wisner B, Blaikie P, Cannon T, Davis I 2004 At Risk: Natural Hazards, People's Vulnerability, and Disasters. Routledge.
[7] UNISDR 2017 Country Assessment Report for Indonesia: Strengthening of Hydrometeorological Services in Southeast Asia.
[8] Apip, Sagala S, Pingping L 2015 Overview of Jakarta Water-Related Environmental Challenges. United Nations University-IAS.
[9] Saut Sagala, Dodon Yamin, Lutfiana D, Ramanditya Wimbardana 2013 Alih Fungsi Lahan Rawa dan Kebijakan Pengurangan Risiko Bencana Banjir: Studi Kasus Kota Palembang. https://doi.org/10.13140/RG.2.1.2763.1206.
[10] BPS Kota Bandung 2020 Kecamatan Astanaanyar dalam Angka.
[11] Badan Pusat Statistik, Jakarta. 2021.

[12] Rianawati E and Sagala S 2014 Communal Based Flood Mitigation Measures in Bandung City.
[13] Bandung City Spatial Plan 2011-2031. n.d.
[14] Davis M, Naumann S 2017 Making the Case for Sustainable Urban Drainage Systems as a Nature-Based Solution to Urban Flooding 123–37. https://doi.org/10.1007/978-3-319-56091-5_8.
[15] Nurhikmah D, Akmalah E 2016 Pemilihan Metode Sistem Drainase Berkelanjutan Dalam Rangka Mitigasi Bencana Banjir Di Kota Bandung **12**.
[16] Jeffries C, Scotland & Northern Ireland 2004 Forum for Environmental Research. SUDS in Scotland: the monitoring programme of the Scottish Universities SUDS monitoring programme : final report. Edinburgh: SNIFFER.
[17] Uvini Srishantha, Upaka Rathnayake 2017 Sustainable urban drainage systems (SUDS) what it is and where do we stand today? Engineering and Applied Science Research **44** 4. https://doi.org/10.14456/EASR.2017.36.
[18] Jayawardena AW 2015 Hydro-meteorological Disasters: Causes, Effects and Mitigation Measures with Special Reference to Early Warning with Data Driven Approaches of Forecasting. Procedia IUTAM **17** 3–12. https://doi.org/10.1016/j.piutam.2015.06.003.
[19] UNISDR. Terminology on Disaster Risk Reduction 2009.
[20] IFRC. World Disasters Report 2012.
[21] Directorate-General for Climate Action (European Commission). Going climate-neutral by 2050: a strategic long term vision for a prosperous, modern, competitive and climate neutral EU economy. LU: Publications Office of the European Union.
[22] Sulasmi 2014 Analisis Kerentanan Kebakaran Permukiman Menggunakan Sistem Informasi Geografis Di Kecamatan Depok Kabupaten Sleman. skripsi. Fakultas Ilmu Sosial.
[23] Merz B, Thieken AH, Gocht M 2007 Flood Risk Mapping At The Local Scale: Concepts and Challenges. In: Begum S, Stive MJF, Hall JW, editors. Flood Risk Management in Europe: Innovation in Policy and Practice, Dordrecht: Springer Netherlands 231–51. https://doi.org/10.1007/978-1-4020-4200-3_13.
[24] Birkmann J 2006 Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies. United Nations University Press.
[25] Poleto C, Tassi R 2012 Sustainable Urban Drainage Systems. Drainage Systems, InTech. https://doi.org/10.5772/34491.
[26] Griffiths J 2016 Sustainable Urban Drainage. Reference Module in Earth Systems and Environmental Sciences. https://doi.org/10.1016/B978-0-12-409548-9.10203-9.
[27] Woods Ballard B, Wilson S 2015 Udale-Clarke H, Illman S, Scott T, Ashley R, et al. The SuDS Manual.
[28] European Commission 2012 Guidelines on best practice to limit, mitigate or compensate soil sealing.
[29] Goulden S, Portman M, Carmon N, alon mozes T 2018 From conventional drainage to sustainable stormwater management: Beyond the technical challenges. Journal of Environmental Management 219. https://doi.org/10.1016/j.jenvman.2018.04.066.
[30] Kellagher R, Laughlan C. Use of SUDS in high density developments. Guidance manual 2005. https://eprints.hrwallingford.com/550/ (accessed July 21, 2021).
[31] Jiménez Ariza, Martínez, Muñoz, Quijano, Rodríguez, Camacho, et al 2019 A Multicriteria Planning Framework to Locate and Select Sustainable Urban Drainage Systems (SUDS) in Consolidated Urban Areas. Sustainability;11:2312. https://doi.org/10.3390/su11082312.
[32] Barros Ramalho Alves P, Alexandra Alves Rufino I, Hermínio Cunha Feitosa P, Djordjević S, Javadi A 2020 Land-Use and Legislation-Based Methodology for the Implementation of Sustainable Drainage Systems in the Semi-Arid Region of Brazil. Sustainability **12** 661. https://doi.org/10.3390/su12020661.

[33] jabar.tribunnews.com 2020 Banjir Terparah di Astanaanyar Kota Bandung, Tinggi Air Capai 2 Meter di RW 07 Kelurahan Cibadak (Worst Flood in Astanaanyar, Bandung City, Water Height Reaches 2 Meters in RW 07 Cibadak Neighbourhood).
[34] Nóblega Carriquiry A, Sauri D, March H 2020 Community Involvement in the Implementation of Sustainable Urban Drainage Systems (SUDSs): The Case of Bon Pastor, Barcelona. Sustainability **12** 510. https://doi.org/10.3390/su12020510.
[35] Cotterill S, Bracken LJ 2020 Assessing the Effectiveness of Sustainable Drainage Systems (SuDS): Interventions, Impacts and Challenges. Water **12** 3160. https://doi.org/10.3390/w12113160.
[36] Zhou Q 2020 A Review of Sustainable Urban Drainage Systems Considering the Climate Change and Urbanization Impacts. Water 2014;6:976–92. https://doi.org/10.3390/w6040976.