Linking engineering approach and local wisdom in water sensitive urban design as an adaptation strategy to climate change

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Abstract. The impacts of climate change on cities have been clearly identified. Climate change threatens the cities on urban infrastructure, urban life and well-being, urban environment and entire urban system. One of the most obvious impacts of climate change on urban system is the presence of more vulnerability of cities on urban floods due to global sea rise. This is particularly valid for coastal cities. While mitigation strategies could not be comprehensively completed in short time, the adaptation strategies could, therefore, be undertaken to complement the overall strategies to minimize the impacts. An engineering approach can be done at micro-level but should not be the only solution among many possible ways out. Urban planning and design, on the other hand, could be implemented at macro-level. Water sensitive urban design aims at minimizing the negative impacts of water-associated delinquencies through city planning and design. This study attempts to juxtapose the possible engineering approaches to cope with the impacts of climate change in the city at individual micro-level buildings as a way of the urban citizens to adapt to climate change impacts. The engineering solutions proposed in this study are discovered from various studies around the world and adjusted to local conditions taking into account locally available technologies for proper suitability and the solutions are therefore technologically possible, locally adaptable and environmentally friendly. The local wisdom on climate change adaptation itself has been observed in Southeast Asian countries.

1. Introduction
It has been well known that one of the impacts of climate change in the urban area is urban flood, due to various causes associated with climate change such as the increase sea level, increase rainfall depth and intensity, or more drought incidents [1]. The adverse impact of the phenomenon in city may be on urban infrastructure, urban life, and well-being, urban environment or urban system as a whole. It can also be simply said that flood hampers city. Urban development, on the other hand, including housing, industry and infrastructure development would also disturb and bring the impacts on water resources [2]. This stalemate hinders urban well-being and there must be an initiative to deal with water-associated climate change impacts. Various strategies to cope with climate change impacts were grouped into adaptation and mitigation strategies [3-5].

Three essential elements of the urban domain, which are closely associated with climate change adaptation strategy, are urban planning, land use planning, and water resources management. If this intersection is used as the basis of minimizing the negative impacts of urban flooding as an adaptation strategy, then water-sensitive urban design would come into picture as a result of the cross-section. The cross-section of urban planning, land use planning, and water resources management form a water sensitive urban design towards climate change adaptation strategy is exhibited in Figure 1.
One of the impacts of climate change is the frequent flood in urban areas [6-7]. The responses to coping with this episode could be in several forms, for instance, mitigate the causes of climate change and flood, or if mitigation strategy is not possible, adjust our life to the flood characteristics [8],[1] and [9]. This approach can be summarized into one action of water sensitive urban design to adapt the city to the impacts of climate change. Water sensitive urban design aims at ensuring the well-being of the citizens and the livability of the city while helping to protect and improve the health of water bodies and their ecosystems and to reduce environmental impacts of water to the city [10-11].

Based on studies by [12] and [13], there are several guiding principles in implementing water sensitive urban design to cope with the impacts of climate change. The guiding principles include (1) water management must be streamlined into the land use planning and urban development process (2) water management must consider conservation of biodiversity and ecological integrity not only at city level but also at regional level and river catchment level (3) water body must be protected from adverse pollution and ensure perpetual provision of water sources to the city (4) destructive power of water must be minimized to lessen its adverse impacts (5) some adjustments on urban infrastructure development would be necessary to avoid the impacts on urban flooding (6) structural and non-structural mitigation to minimize impacts of urban flooding must be done in integrative and coordinative manners. By these principles, an engineering approach with the root of local wisdom of Southeast Asian countries can be applied as adaptation strategies particularly with respect to urban flooding problems.

Findings by [14] asserted that urban design is a collaborative and multi-disciplinary process of shaping the physical setting for life in cities, towns, and villages. Urban design involves the design of buildings, groups of buildings, spaces and landscapes, and the establishment of frameworks and processes that facilitate successful development. Within the framework of water sensitive urban design, the urban design process and water management process must mutually complement one another. According to [15], local knowledge and local wisdom of indigenous people are capable of solving various problems they encountered through a long-life learning process. They learn from nature and experience, as nature knows best to adapt something through evolution process. The best and the fittest will prevail.

2. Mitigation and adaptation strategies for climate change
Within the climate change framework, mitigation strategies are actions taken to reduce or limit greenhouse gas emissions. On the other hand, adaptation strategies aimed at reducing the vulnerability to the effects of climate change. For this purpose, study by [16] highlighted some following essential points in implementing the adaptation strategies: (a) Prioritize adaptation efforts in communities where vulnerabilities are highest and where the need for safety and resilience is greatest, (b) build projected climate change-related trends in today’s risk and vulnerability assessment based on current climate variability, (c) fully integrate adaptation into longer-term national and local sustainable development.
and poverty reduction strategies, (d) prioritize the strengthening of existing capacities – among local authorities, civil society organizations, and the private sector – to lay the foundations for the robust management of climate risk and the rapid scaling up of adaptation through community-based risk reduction and effective local governance, (e) develop robust resource mobilization mechanisms for adaptation that ensure the flow of both financial and technical support to local actors, (f) leverage the opportunities in disaster prevention and response, through improved early warning systems, contingency planning and integrated response, to promote effective community-based adaptation and risk reduction.

The above points need further elaboration in order to work properly for the implementation at the local level. Preparing a water sensitive urban design, as a strategy of climate change, must consider different levels of planning process and wide variety of activities associated with climate change, as partly exhibited in Figure 1. The design should firstly commence with a land-use plan. The plan should result in a spatial arrangement that is able to minimize the production of greenhouse gas emissions (mitigation strategies) and to minimize the impacts of climate change (adaptation strategies). This plan includes: (a) Road and network arrangement: encouraging public transport, ride-sharing, discouraging private transport, and within walking distance principles, (b) Buildings: promoting energy-efficient buildings, promoting green buildings, and low-impact building materials, (c) open space and greeneries: increasing urban forestry to maximize the capacity of urban sequestration, increasing the capacity of air pollution absorption, (3) reducing the incidents of urban heat island, and expanding the urban lakes and other water bodies to modify the micro-climate in the city, (d) housings: increasing the capacity of rainwater harvesting, reducing the quantity of surface run-off, avoiding flood inundation by elevating the floor, (e) zoning: a zonation strategy can be applied by considering the vulnerability of particular part of the city on disasters associated with climate change, (f) urban ecosystem: Minimizing the disturbance to natural ecosystem exists within the city and periphery.

These elements must be a presence in the land use plan, as a guide to urban development to cope with climate change. In line with the land use plan, water resources planning that will directly or indirectly affect the city should also be brought on board, towards a comprehensive approach in minimizing the impacts of climate change. The following points can be considered in water resources planning and management to minimize the impacts of climate change: (a) Climate change will like to disturb the water quality due to more frequent drought of flood. A coping strategy to cope with both at once is by reserving the water through artificial or natural reservoir. Artificial reservoir can be created by constructing a dam. The natural reservoir is created by expanding the urban forest. This urban forest can also serve as carbon sequestration. These two kinds of reservoirs basically manage low water (drought) and high water (flood) conditions as well as water quality. (b) Climate change impacts may also be reflected in the increase of evapotranspiration rates from plant, soil and open water. Urban water authority must take necessary actions to avoid stressful plants and trees in the urban parks, urban landscapes or forest, and dehydrated soil through irrigation. (c) The prolonged drought may also create water pollution in non-perennial rivers, ephemeral rivers, and urban drainage, due to less discharge and more household wastewater discharged to the channel. A periodical discharge during the seasons would help to reduce water pollution. (d) Increased water demand and irrigation needs due to urban water use. The possible response to this matter is building artificial and natural reservoir.

The above strategies are mostly mitigation solutions. So, how urban citizens adapt to climate change impacts, the subsequent section discusses the strategy at local level with respect to water sensitive urban design.

3. Learning from local wisdom and local technology

Local wisdom contains numerous philosophical learning evidence from timeless learning process and learning from nature practices [17, 18]. This notion has brought many identifiable solutions to persistent natural phenomena encountered by local people. From the everlasting learning and experience, the local people derived responses to the phenomena as reflected in their creations such as
local technology-based houses as a result of local wisdom. A few examples of local technology products as a response to frequent flood or wild animal disturbance or earthquakes are the construction of houses with elevated floors. This local technology has been applied in rural Indonesia, Malaysia, and Thailand. Figure 2 shows a house with elevated floor, which is initially intended to avoid floodwater or disruption by wild animals. However, in modern times, this type of house is rather designed for sentimental purposes only. The height of floor was designed based on deepest flood water has ever happened, if the elevated floor is to avoid floodwater. If it is to evade the disruption from wild animals, the height of floor depends on the disruption itself.

![Figure 2. House with elevated floor to avoid flood. (Source: carameriasbunga.blogspot.com, retrieved 07/05/19)](image)

The response of local technology on earthquakes has long been implemented in Central Sulawesi, Indonesia as shown in Figure 3. The technology contains three purposes: conserving tradition, reducing damage to houses by earthquake, and safety from wild animals. The flood is not considered since the location is not flood-prone area. There are two obvious features in the earthquake-resistant house, first, the introduction of lattice works, the interlacing wood bars to resist the horizontal force of earthquake, and second the separation of understructure and superstructure to dampen the force. By resisting or dampening the horizontal force of earthquake, the overall structure will be safe. This type of house buildings is frequently found in rural areas and where flood or earthquake disasters frequently take place.

Other local wisdom based technology on housing is the use of steel roof, to avoid the overload of roof due to sand material ejected by volcanic eruption. This house used usually zinc-roof sheets, to improve the ductility. In case that the roof was made from straw baler, the main purpose is to minimize leakage during rainfall, by accelerating the velocity of rainwater flowing through the roof. This local-based roof technology was found in the many villages in Indonesia. However, modernization and well-being improvement have made this local wisdom is no longer used.
Learning from the presence or once existence local wisdom based technology, and by using current technology in civil engineering, keeping the principles of technologically possible, locally adaptable and environmentally friendly, various adaptation strategies associated with water-sensitive urban design can be done at the local level, as discussed in the subsequent section.

4. Various adaptation strategies at local level
Adaptation strategies and mitigation strategies of climate change complement one another. Adaptation strategies are encouraged when mitigation strategies cannot be done or impossible to be done for some reason. Therefore, mitigation strategies are more stimulating than adaptation strategies since they mitigate the source of climate change. One of the most significant impacts of climate change on urban citizens is flood. Many coastal cities around the globe are vulnerable to flood due to heavy rain and high overland flow and augmented by the sea level rise. A report by [19] stated that the global sea level has been rising over the past century, and the rate has increased in recent decades. In 2014,
Global sea level was 2.6 inches above the 1993 average—the highest annual average in the satellite record (1993-present). Sea level continues to rise at a rate of about one-eighth of an inch per year. This will have a significant impact on coastal cities in addition to the existing changes in the urban landscape. The changes of urban landscapes from natural environment into built-environment will increase the surface runoff because of the decrease of infiltration capacity and increase of runoff coefficient, and therefore, the encouraging factors of flood could be many times larger than discouraging factors.

In the cities where climate change impacts of an urban flood are significant, while mitigation strategies are also being implemented, but the flood cannot be reduced significantly, the citizens must adapt to urban flood by adopting a principle of living with flood. Living with flood principle is an effort to harmoniously live side-by-side with the wish of nature. Rather than fight the flood, mankind adjust to the flood. This principle can be implemented in some ways at local level.

Avoiding flood water to enter the house can be done by elevating the house floor in several ways, among others, by embankment and pile. They work with the same principle. However, while pile replaces the ignorable volume of floodwater, the embankment takes up remarkable volume of flood. Therefore, if everyone in the area uses the embankment method to elevate their house floor, the fact is they only shift the flood from the area to somewhere else, and it does not solve the root of the problems. Figure 5 shows the flood water occupies the same place as the house. The access to house can be facilitated by making a ramp or stairs. Transportation during flood water can be carried out by using boat. The floor elevation is at least 1 meter above expected flood level. The flood level itself can be analyzed by using statistical model. Roads in the area should also be constructed from water-proof material like concrete, and it will thus withstand under the water for a relatively long time. Raised floor by using embankment is another option of adaptation strategy to flood, as one of the climate change impacts. Embankment must be stable from erosion and sliding due to loads (house) and flood water.

In case the construction of the house was done prior to identified flooding problems, then an elevated floor could not be implemented, a flood barrier as a way of adaptation to the urban flood. In this case, a flood barrier encircling the house can be constructed. The barrier can be made from concrete, waterproof brick or soil embankment as shown in Figure 6.

Changes in land use would consequently alter the imperviousness of the land. This exerts an essential influence on rainfall-runoff relationship due to changes in the hydrological-ecological process in urban areas [20]. They argued that the growth of impervious surfaces in urban areas is directly associated with urban development particularly in terms of human activities and habitation through the construction of building, parking lots, roads, and other structures, and therefore an intense urbanization leads to the disturbance of natural landscapes and replacement of vegetation-covered surfaces with impervious surfaces (Figure 7). The factors that influence the variations in urban

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**Figure 5.** Elevated house floor by (a) Pile - left (b) Embankment - right
hydrology include increased runoff, decreased recession time, decreased groundwater recharge and decreased base flow [21,22].

Figure 6. Flood barrier.

Figure 7. Pervious pavement.

From this theory, we can safely say that when the use of the land is changing due to any activities of urban development from natural environment to built-up environment, the most visible and sensible immediate impacts are on increasing flood probability and loss of biodiversity when the loss of biodiversity could be off-set somewhere else or even neglected due to species abundance. But, a higher probability of getting urban flood could not be compensated. The increase of urban flood probability can be explained through (1) rainfall-run-off relationship (2) land surface alteration.

By the rational formula, the flood can be modified or reduced by minimizing the run-off coefficient while increasing the infiltration rate. The modification of runoff coefficient can be done through increased permeability of the land, for instance, through pervious pavement as exhibited in Figure 8. However, this effort would not be effective if the subgrade soil consists of clay with extremely small hydraulic conductivity. In this case large run-off could not be avoided, and the best solution is to quickly drain all the water flow through drainage channel or river with sufficient capacity. If the channel capacity is also limited because of flat landform, then leave the land to be flooded temporarily and back to the approach as shown in Figures 5 and 6.
A rainfall-runoff relationship can be expressed by a rational formula. A sample of many runoff coefficients is presented in Table 1.

Table 1. Runoff coefficient.

| Description of Area          | Runoff Coefficient (C) |
|-----------------------------|------------------------|
|                             | Flat  | Rolling | Hilly |
| Pavement and roof           | 0.90  | 0.90    | 0.90  |
| Gravel Pavement             | 0.85  | 0.85    | 0.85  |
| Apartment Dwelling Area     | 0.50  | 0.60    | 0.70  |
| Residential Area            | 0.70  | 0.75    | 0.80  |
| Industrial Area             | 0.60  | 0.70    | 0.80  |
| Parks and Cemeteries        | 0.10  | 0.15    | 0.25  |
| Woodland and Forest         | 0.10  | 0.15    | 0.20  |
| Unimproved Areas            | 0.10  | 0.20    | 0.30  |

Source: Oregon Hydraulics Manual, App. F (2014)

In addition, a rational formula is expressed in the following form:

\[
Q = 0.278 \times C \times I \times A
\]

Where:
- \(Q\) is discharge in m³/sec
- \(C\) is runoff coefficient
- \(I\) is rainfall intensity in mm/hour
- \(A\) is drainage area/catchment area in km²

Adaptation by all citizens on the impacts of climate change like an urban flood can also be implemented through more egalitarian way. In this case, all individual citizens are asked to adapt the urban flood by providing underground storage. This storage, depending on its objectives, can serve as recharging storage into groundwater or as a mean of rainwater harvesting if the area frequently suffers from shortage of water. In case the objective of underground storage is to cope with the flood, then the analysis to determine the volume of the underground storage can be done this way: to ensure fairness in distribution, storage which is provided by each in the community should be based on the area of individual land plots. The local authority, in this case, determines the design rainfall that will be regulated by the decentralized system. For example, a design rainfall is designated as \(h\) mm/hr. The individuals, therefore, provide storage according to their land plot area, defined by \(S_i = 0.001 \times A_i \times h\times D\), where \(S_i\) is storage that must be provided individually (m³), \(A_i\) is individual land plots area (m²), \(h\) is design rainfall (mm/hour) determined by the local authority, and \(D\) is projected rainfall duration (hour). The best situation will be created if those storages are installed underground since this storage enables collected rainfall to recharge into groundwater. In the long run, it will provide sufficient groundwater source and ultimately lead to sustainable development (Figure 8). Rainwater that falls within an individual land parcel is collected, including through pipes from the roof-top, and discharged into an underground tank for subsequent recharge into groundwater.

In case the objective of underground storage is to cope with prolonged drought i.e. rainwater harvesting, then the volume of storage is determined based on individual capacity to construct the
storage, the more you capable to construct the storage the more storage volume. Both objectives cannot be combined since the function is different. The underground storage to feed the groundwater needs no waterproof tank since the water within the storage can be released gradually to groundwater through seepage in the soil. On the other hand, rainwater harvesting storage is to contain water as much as and as long as possible. The underground storage to feed groundwater also cannot be implemented in a soil where hydraulic conductivity of the soil strata is significantly low such as clay. Rainwater harvesting, on the other hand, is independent of soil type and can be constructed above the ground. Complementing program of low impact development (LID) and sustainable urban drainage system (SUDS) could be reinvigorated to reinforce the impacts of water-sensitive urban design for accomplishing multiplier effects not only dealing with water quantity but also water quality including environmental quality.

![Underground storage](image)

**Figure 8.** Underground storage.

5. **Concluding remarks**

Water sensitive urban design does not necessarily in the form of very complicated concepts and guidance, which need very complicated, large scale and difficult approaches. Concept wise, water sensitive urban design must be comprehensive with a concept of ranging from a very simple to complicated approach, can be inexpensive to very costly supporting activities or infrastructure. It can also be implemented through practical and community-based activities. The above practical and community-based approach can certainly be done by individual with low-cost activities. If the concept is too complicated, the design implementation would not be able to involve community at large, and therefore the government is the sole implementer of the concept. This approach is incorrect, since the involvement of all stakeholders particularly community, as the end-users, is a must.

Water sensitive urban design should not only be the singular program of adaptation strategies, rather complemented by other programs to reinforce and extend the impacts. The principles of technologically possible, locally adaptable and environmentally friendly employed in water-sensitive urban design would have a couple of advantages when implemented for its local and natural features.

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