The Study of Urban Energy Balance and Water Balance in Bashundhara Residential Area, Dhaka

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Abstract. Dhaka is a densely populated megacity. Many parts of this city are overcrowded. The city is now expanding on all sides, but on the eastern front, there are some major developments by public and private organizations. Bashundhara residential area is one of them which is being developed by the Bashundhara group on eastern the side of Dhaka city since the 1980s. There are some urban microclimatic challenges in this area, such as poor water drainage system, waterlogging, natural canals are blocked by the new development, no parks, playfield within the studied area, set back rule violation by landowners, little vegetation contributed to an imbalance in Energy and Water cycle. This study focused on the study of the current situation and possible development through altering and adding surface pavement, vegetation, and trees, reducing building footprint, enlarging water surface by remote sensing technology using qGIS software. Though there are some limitations of this study, the results show strong scope for the development of the existing microclimatic situation in Bashundhara residential area as well as knowledge from this exercise can be applied to other parts of Dhaka.

1. Introduction
According to a United Nations report, in 2011 about four billion people lived in cities; the number of urban dwellers is expected to grow to over 60% of the earth's population by 2050 [1]. With growing cities, highly populated areas mandate cities to develop either vertically or horizontally, resulting in more released anthropogenic heat, a higher absorption of solar radiation, and eventually a reduced long-wave emission to sky which result in a warmer climatic condition, known as urban heat island (UHI) [2]. In the early 19th century, scholar Lake Howard firstly measured and discussed the UHI effect when studying urban climate in London, England [3].

Dhaka is one of the fastest growing megacities in the world. As a result of unplanned development the city is suffering from urban heat island effect and air pollution [4]. Large chunk of low land as well as water bodies around the Dhaka city are illegally filled and used for housing. This land filling are causing water and energy imbalance through blockage to natural water flow as well as rainwater runoff [5]. One of the example of those unplanned development is the Bashundhara Residential Area on the eastern part of the Dhaka City since 1980s. In this study urban heat island (UHI) effect is studied based on energy balance and water balance proposed by T.R.Oke [6]. Through this study it has been observed that energy balance can be altered positively to reduce UHI effect through manipulation of building footprint and increasing vegetation into the area.

In this study qGIS software is used to analyze the energy balance and water balance data. The qGIS is an open source software. The Urban Multi-scale Environmental Predictor (UMEP) is a plugin of the qGIS software. It is used to study the urban radiation, energy and water balances using commonly...
measured modeled meteorological variables and information about the surface cover. It is based on the evaporation interception approach proposed by Grimmond et al. 1991 [7].

1.1 Literature review

Urban Heat Island effect causes the increase of heat in cities. The elevated temperature triggers heat related diseases and premature deaths in the cities. Moreover, the elevated air and surface temperatures during UHI events increase the city scale mean and peak cooling energy demand due to lower efficiency of HVAC systems in higher temperatures as well as a significant drop in the thermal comfort level [3]. Studies have shown that an air temperature increase of 1 ◦C for an urban area could lead to an electricity consumption increase up to 8.5% [8].

![Figure 1. Schematic depiction of the radiative exchanges in a polluted urban boundary layer][6]

Two most distinguishing features of tropical urban Surface Energy Balance SEB is the importance of direct solar radiation within net all wave radiation (Q*) for daytime urban exchange of momentum, heat and water vapor, and the seasonality of the relationship between Sensible (H) and latent (LE) heat. According to Barradas, Tejeda-Martínez, and Jáuregui [9], net radiation was higher during the dry season and was partitioned between H and LE in the order of 69% and 25%, respectively. However, during the wet season this was reversed to 27 and 70% respectively, and the total was lower [10]. Estimating QF is very difficult in the tropics due to the lack of information. The significant diurnal change in the total stored energy flux could be an important driver of the UHI phenomenon in a tropical city but the relationship between ΔQs and UHI is not so clear. The large difference between the day and diurnal storage (50% vs 27%) might provide an explanation. Tropical UHIs are strongest during the pre monsoon and monsoon nights but surface temperature differences are strongest during the day and during the pre monsoon only [10].

UHI mitigation strategies in tropical cities is not straight forward. Ventilation is as important as shading. Vegetation, green roof and cool roofs, pavement need great attention and careful deployment in city to mitigate the UHI. One study shown Sharmin et al. [11] ‘traditional’ urban form with diverse shapes, setbacks, non uniform relationship to streets, varied compactness performs much better than ‘planned’ urban areas characterized by uniform building heights, equal building separation and plot sizes. The latter leads to both harsher thermal comfort conditions and higher air temperatures. A simulation exercise done by Martins et al. [12] show that surface albedo, aspect ratio and distance between buildings together account for around 80% of the variations in solar radiation in tropical cities. Which points toward an integrated mitigation strategies for tropical UHI.

1.2 Methodology & Limitations

To study the UHI effect in urban context more effectively Local Climatic Zones are proposed by [13] which provides frame work for research and standardizes global exchanges of urban temperature observations. The landscape universe consists of 17 standard LCZs, of which 15 are defined by surface structure and cover and 2 by construction materials and anthropogenic heat emissions. Each LCZ should have a minimum diameter of 400 – 1,000m. For the purpose of this paper a portion of Bashundhara Residential Area is selected to study urban energy balance and water balance as well as to propose mitigation strategies.
UMEP (Urban Multi-scale Environmental Predictor) is a city-based climate service tool. It combines models and tools essential for climate simulations. It is an open-source tool, the software is written as a plug-in to QGIS, a cross-platform, free and open source desktop geographic information system (GIS) application. It includes tools such as green infrastructure on runoff (SUEWS) to enable users to input atmospheric and surface data from multiple sources, to characterize the urban environment, to prepare meteorological data for use in cities, to undertake simulations and consider scenarios, and to compare and visualize different combinations of climate indicators [6].

Surface Urban Energy and Water Balance Scheme (SUEWS), which calculates energy and water balances at the neighborhood scale. The foundations of SUEWS, the urban evaporation-interception scheme of Grimmond and Oke [6] and the urban water balance model of Grimmond et al. [14]. The goal is to provide a widely applicable model for researchers and urban planners which could be embedded into larger scale models or operate on a standalone basis. [15]
For urban areas the water balance of the external environment can be written proposed by Grimmond et al., [15]:

\[ P + I_e + F = E + R + \Delta S \] [mm h\(^{-1}\)]

Through evaporation the water balance is linked to the energy balance which in urban areas is written as per T. R. Oke, [6]:

\[ Q^* + Q_F = Q_e + Q_H + \Delta Q_S \] [W m\(^{-2}\)]

Where \( Q^* \) the all wave radiation
\( Q_F \) is the anthropogenic heat flux, \( Q_H \) is the sensible heat flux, \( Q_e \) is the latent heat flux, \( \Delta Q_S \) is the storage heat flux

Since the DSM (Digital Surface Modelling) data is in progress in Dhaka. The Dhaka climate file is also in the process of up-gradation, so the analysis is done with the currently available climate file at the time of research. LAI or Leaf Area Index for whole Dhaka is in progress.

2. Analysis and result

Bashundhara residential area is located on the eastern side of Dhaka city. It is a private land development project by Bashundhara Group since the 1980s. It was developed primarily by filling up low flood plain and water bodies on the eastern side of Dhaka city. As a consequence, there is a water drainage problem in this area. Today it has 17 blocks. But block A to D are the most densely populated. For urban energy balance and water balance purpose densely populated blocks are selected within 1000meter diameter. Within this circle it is observed based on field survey that building surface fraction 40%, impervious surface fraction is 41%, pervious surface fraction 19%, height of roughness element is around 24meter, terrain roughness class 7, sky view factor (SVF) is around 0.4, average aspect ratio which is urban canyon height to width ratio, is around 1.75. Based on the above-mentioned parameters the selected 1000meter diameter area in Bashundhara falls into the LCZ 2 category.

Based on the field survey in the Bashundhara residential area following parameters are provided in the SUEWS dialog box. Mean building height 22 meters, plan area index 0.4, paved 0.41, building 0.4, evergreen trees 0.019, deciduous trees 0.001, grass 0.029, bare soil 0.001, water 0.14, mean vegetation height 13.1, plan area index 0.02.

After running the SUEWS with the existing data it is observed that direct solar radiation heat flux \( Q^* \) is highest in April to October, sensible heat flux \( Q_H \) is highest from October to March, soil moisture deposit SMD is highest from April to September which corresponds with the precipitation patterns. Storage heat flux \( \Delta Q_S \) is lowest during the monsoon period from June to September due to the evaporative cooling in that period. The interesting thing in water balance is that the storage and runoff are almost equal. It corresponds to the fact that in the Bashundhara residential area there is very little scope of water storage and proper drainage system as a result during heavy rainfall water is stored on the road and later this water is drained out gradually. That is why the runoff and storage curve is quite similar.

The parameters in the SUEWS plugin of qGIS software are changed to see the impact or change in urban energy balance and water balance in Bashundhara Residential Area. It has been observed that if
the building footprint is reduced by 15% and the trees (evergreen and deciduous combined) are increased 5 times, the anthropogenic heat flux $Q_F$ is significantly reduced in the summer season from April to June.

![Figure 2. The selected study area in Bashundhara residential area](image)

This is due to less energy consumption by less building for space cooling in the summer season. The increased trees mean that evaporative cooling through evapotranspiration as a result evaporation is increased in water balance. And the shading of trees reduces the storage heat flux $\Delta Q_S$ in energy balance. As evaporation increased the latent heat flux $Q_E$ and the anthropogenic heat flux $Q_F$ is decreased as a result the sensible heat flux $Q_H$ is decreased. Since the sensible heat flux, $Q_H$ is related to the latent heat flux $Q_E$ and the anthropogenic heat flux $Q_F$.

![Figure 3. Urban energy and water balance after running the SUEWS with existing data](image)
3. Conclusion

Urban Heat Island effect is a global phenomenon. Tropical countries are suffering from UHI due to unplanned rapid urbanization, deforestation, hard surface coverage, grabbing and filling wetland as well as water bodies. As a result, there is a distinct temperature difference between cities and villages. To tackle Urban Heat Island it is necessary to study and monitor urban energy balance and water balance. UMEP is an excellent tool to do that and its SUEWS application can play a crucial role to modify and adjust urban fabric by urban planners and researchers. This study showed that reducing building footprint and planting more trees can reduce anthropogenic heat as well as storage heat. At the same time through evapotranspiration by trees temperature can be lowered. Which supports the research findings by Sharmin et al. [12]. But unfortunately, there is a shortage of resources in many tropical cities. The Digital Surface Modelling, Leaf Area Index will be conducted for whole Dhaka city in near future which will fulfill the requirements for future researchers and thereby will provide an opportunity to study and tackle Urban Heat Island in Dhaka with and open up the vast field for remote sensing technology to be used in other tropical cities.

4. References

[1] Akbari, H., & Kolokotsa, D. Three decades of urban heat islands and mitigation technologies research. Energy and Buildings, 2016, pp 834-842, https://doi.org/10.1016/j.enbuild.2016.09.067
[2] Mirzaei, P. A. Recent challenges in modeling of urban heat island. Sustainable Cities and Society. Vol 19, 2015, pp 200-206. https://doi.org/10.1016/j.scs.2015.04.001
[3] Yang, L., Qian, F., Song, D. X., & Zheng, K. J. Research on Urban Heat-Island Effect. In Procedia Engineering. 2016, pp 11-18. https://doi.org/10.1016/j.proeng.2016.10.002
[4] Tawhid, K. G. Causes and Effects of Water Logging in Dhaka City, Bangladesh. TRITA-LWR Master Thesis Department of Land and Water Resource Engineering Royal Institute of Technology, 2004, Stockholm, pp 1-63
[5] Alom, M., & Khan, Z. H. Environmental and Social Impact Due to Urban Drainage Problems in Dhaka City, Bangladesh. International Journal of Engineering and Advanced Technology (IJEAT), 2014, 3(6), pp 128–132.
[6] Stewart, I. D., & Oke, T. R. Local climate zones for urban temperature studies. Vol 93. Issue 12. December 2012, pp 1879-1900. https://doi.org/10.1175/BAMS-D-11-00019.1
[7] Grimmond, C. S. B., & Oke, T. R. An evapotranspiration - interception model for urban areas. Water Resources Research, 1991. 27(7), pp 1739 – 1755. https://doi.org/10.1029/91WR00557
[8] Karakounos, I., Dimoudi, A., & Zoras, S. The influence of bioclimatic urban redevelopment on outdoor thermal comfort. 2018. Energy and Buildings, Vol 158, 2018, pp 1266-1274. https://doi.org/10.1016/j.enbuild.2017.11.035

[9] Víctor L. Barradas, Adalberto Tejeda-Martínez, Ernesto Jáuregui, Energy balance measurements in a suburban vegetated area in Mexico City, Atmospheric Environment, Vol 33. Issue 24-25, pp 4109-4113, 1999. https://doi.org/10.1016/S1352-2310(99)00152-1

[10] Giridharan, R., & Emmanuel, R. The impact of urban compactness, comfort strategies and energy consumption on tropical urban heat island intensity: A review. Sustainable Cities and Society, pp 677-687. 2018. https://doi.org/10.1016/j.scs.2018.01.024

[11] Sharmin, T., Steemers, K., & Matzarakis, A. Analysis of microclimatic diversity and outdoor thermal comfort perceptions in the tropical megacity Dhaka, Bangladesh. Building and Environment. Vol 94, pp 734-750. 2015. https://doi.org/10.1016/j.buildenv.2015.10.007

[12] Martins, T. A. de L., Adolphe, L., Bastos, L. E. G., & Martins, M. A. de L. Sensitivity analysis of urban morphology factors regarding solar energy potential of buildings in a Brazilian tropical context. Solar Energy, Vol 137, pp 11–24. 2016. https://doi.org/10.1016/j.solener.2016.07.053

[13] Lindberg, F., Grimmond, C. S. B., Gabey, A., Huang, B., Kent, C. W., Sun, T., Zhang, Z. Urban Multi-scale Environmental Predictor (UMEP): An integrated tool for city-based climate services. Environmental Modelling and Software, Vol 99, pp 70–87. 2018. https://doi.org/10.1016/j.envsoft.2017.09.020

[14] Grimmond, C.S.B., Oke, T.R., Steyn, D.G., Urban water balance 1. A model for daily totals. Water Resour, Vol 22, pp 1397-1403. 1986.

[15] Järvi, L., Grimmond, C. S. B., & Christen, A. The Surface Urban Energy and Water Balance Scheme (SUEWS): Evaluation in Los Angeles and Vancouver. Journal of Hydrology, 411(3–4), pp 219–237. 2011. https://doi.org/10.1016/j.jhydrol.2011.10.001