TITLE: Modeling CO_2 Restoration Potential of Mangrove Ecosystem of Pakistan to Support Urban Greenspaces and Human Well-Being

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Abstract: Pakistan is facing major climate change challenges since in recent years, the annual mean temperature has increased by 0.5°C in the country. Karachi is the largest city and highly vulnerable to fatal heatwave events trolling maximum deaths and illness in recent years. Coast of Mangrove Forest (MF) plays an important role in daily temperature, local environment, and microclimatic conditions. It is a well-established scientific reality that carbon traps heat in the air, and now observing a dramatic rise in temperature. The study aimed to evaluate the vulnerability of the communities to heat-stress, and categorize the role of Mangrove Ecosystem Services to mitigate future disasters. Coupled models and GIS/RS tools were used to estimate the suitability of MF land-cover to categorize the latent status. Heatwaves during summer for three days were calibrated by the models which resulted that an inundation of CO_2 stress factors, 250 (S-u=1.0) with a rise in temperature up to 44°C with 70% humidity causes more deaths under heat-periods. Our results linked heatwaves with climate warming and extreme weather events, aggravated by rapid urbanization, industrialization, deforestation, emission of CO_2, degradation of MF, and land-use change. Moreover, findings revealed that there is a significant drop-off in urban greenspaces and growth in built-up areas during 1984-2016. In addition, the SILVA-model projected that MF around the city has the ability to absorb CO2 emission up to 55.4 million tons. SILVA-growth projected that 43.61% CO_2 stock can be deposited by MF which contributes 19% of the ecosystem. Model showcase that rehabilitation of 30-mangrove trees per/100m^2 possibly reduce the extreme tide of heat stress, tsunami, CO_2, and improve the air-quality index of the city. This study provides initial assessment and policy directions to rehabilitate MF to promote sustainable cities and societies.

Key Words: CO_2, urban green spaces**,** disaster risk reduction, extreme weather events

1. Introduction

Today, more than 50% (∼3.5 billion) of global and 49.6% of Asian population live in cities. Current growth simulations indicate that by 2050, nearly 6.3 billion people out of an estimated global population of 9.1 billion will be living in urban territories [1]. The rapid urbanization is generally caused by the increase in population and its growth drives the change in land cover and land use pattern. Land cover and land use changes due to urban expansion may have undesirable impacts on local biodiversity, ecology and urban green spaces. Cities occupy just 3 per cent of the Earth's land but account for 60% - 80% of total energy consumption and 75% of total carbon emissions. There are 828 million people living in slums, and the number is rising rapidly. Anthropogenic climate change is a serious issue as established by consecutive IPCC reports and its impacts are clearly visible in the urban areas [2].

Warming of just 1.5 ^{0}C could bring severe consequences for climate risk management. In recent decades, change in climate has made negative impacts not only on all natural and human systems in all continents but also across the oceans (IPCC, 2014). The extreme weather events (EWE) have increased the possibility of extreme disasters. For instance, an increase in the number of most intense tropical cyclones, inland and coastal flooding, landslides, drought, increased aridity, water scarcity, air pollution as well as continuously rising sea levels and storm surges, and the increasing threat of fatal heatwaves have been observed during the last decade or so around the Globe [3–6].

Rising temperature is very frequently reported in Asian countries like Pakistan, India, Srilanka, Afganistan and Bangladesh. In addition to escalating baseline temperature, uncontrolable urbanization causing urban heat island (UHI) effect which further poses a threat to developing nations. According the guidlines of National Disaster Management Authority (NDMA) for the preparation of prepardness action plan state that if the maximum temperature continues to be > 45°C for consecutive two days, it is called a heatwave condition. A heatwave occurs when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5°C [7,8]. Heatwaves are defined as ≥ 2 days with local temperature ≥ 97th percentile for that partular area or community [9]. Heat related illnesses are the leading cause of mortality among weather related natural disasters. Changing patterns of heatwaves are part of the global warming effect and the importance of changes is reinforced by their negative impact on society. Community suseptability and exposure to heatwaves has increased around the world by 126 million people from 2001 to 2018. Meanwhile, at the same time, the working productivity is decreased by 5.6 % globally [10].

The heatwaves are the symptoms of global climate change that causes delay in Monsoon rainfall cycle and extreme weather events aggravated by rapid urbanization, industrialization and motorization which leads to high amount of CO_2 level in air, creates high temperature micro climate heat effect and relativity of Urban Heat Island Effect (UHIE). The main causes of extreme weather events in the Karachi city are deforestation and degradation of Mangrove Forests (MF). Mangrove ecosystem plays important role in daily temperature, local environment and micro climatic conditions of Karachi [21]. Major threats to MF are untreated municipal waste and industrial pollution and are still causing undetermined amounts of damage to the MF. Moreover, communities are overexploiting the MF and trees are used for firewood, building material and fodder in the area. As healthy forests absorb immense amounts of CO_2, providing essential carbon sinks. Mangrove Forests extend over 132,000 ha, representing about 3% of the total forest area of Pakistan, and Karachi alone supporting 97% of the total Mangrove Forests in the country[22,23]. Green spaces in urban surroundings are an asset and facilitate social interactions, wellbeing, human health and recreates alternative livelihoods [24]. Furthermore, cities green space can lengthen the planetary health resilience, nurtured and enhancement of food, energy, water, biodiversity, and ecosystem services. Urban green space improves the quality of cities environment and contributes in improvement of shading; landscaping, evapotranspiration, clean air and the storage of carbon that resulted in maintaining low temperature and energy consumption. Regardless of being different from 'untamed nature', 'urban nature' can sustain long-standing vigorous ecosystem services (ESSs) compare with natural processes. In recent decades, loss of greenspaces, biodiversity, and urban ecology due to rapid urbanization and global warming simultaneously recurring disasters risks. Urban green resilient infrastructure (UGRI) development could be helpful through the green engineering of green infrastructure (GI), as EWEs resiliency tool [24,25].

2. Material and Methods

2.1. Heatwaves Climatology

The sensitivity and impacts of heatwaves vary significantly from area to area and region to region. For example, in summer, multi-days air temperature above 30 degrees in North Europe would be problematic than similar temperature in South Asian countries. For this rationale, heatwaves should be characterized on the bases of high percentile base not on absolute threshold air temperature, because the latter technique does not ensure that acclimatization and local climatology have been accessed. Dataset from June-2015 to May-2018 was collected from Pakistan Meteorological Department (PMD) and NOAA to evaluate observed increase in intensity and frequency of heatwaves spells.

2.2. Data and methodology used

For present study, five main datasets were assessed and analyzed. That include microclimatic data, mortality, remote sensing data for thermal infrared images, land-use change (LUC) and land cover (LC). A system thinking frameworks were developed to classify relationships between Biometeorology of Mangrove Forest and its impacts on local biodiversity and ecosystem services. All the meteorological related data was collected from Pakistan Meteorology Department and other registry data was gathered from local municipal corporations and government offices. The primary dataset was foregathered from Survey of Pakistan (SOP) source, ETM+sensors and Topo sheets of Karachi city <scale: 1:50,000. The present research followed the developed framework (Figure 2) to explain the relationship among the EWE, MF, AQI, CO2 emission and temperature.

2.3.1. Scenario modelling on biodiversity and ESS

The future climate and forest scenario model was developed according to the local climatic conditions, precipitation, plant species, and biodiversity and ecosystem services in the area.

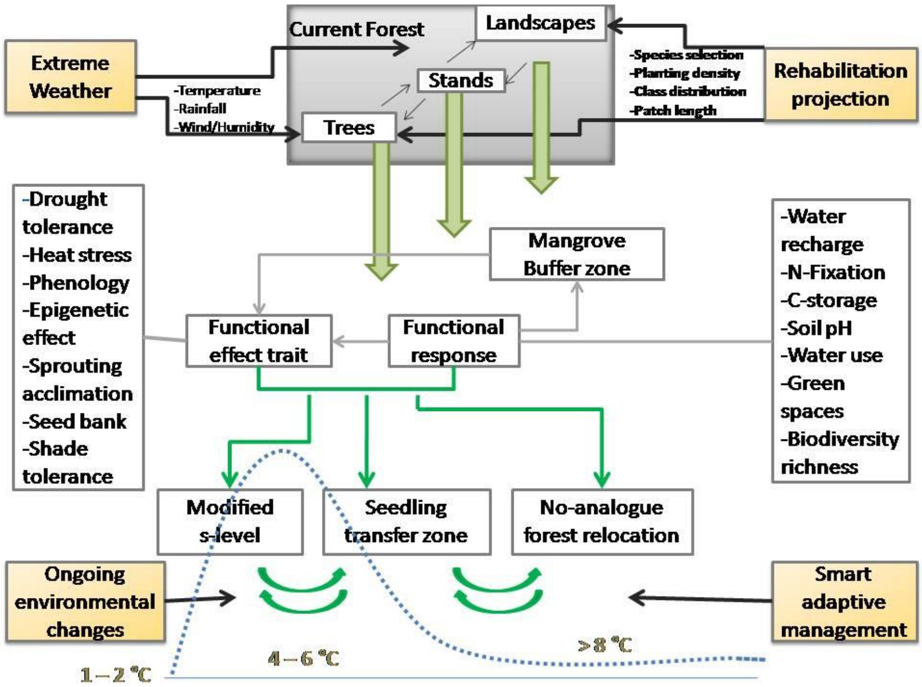
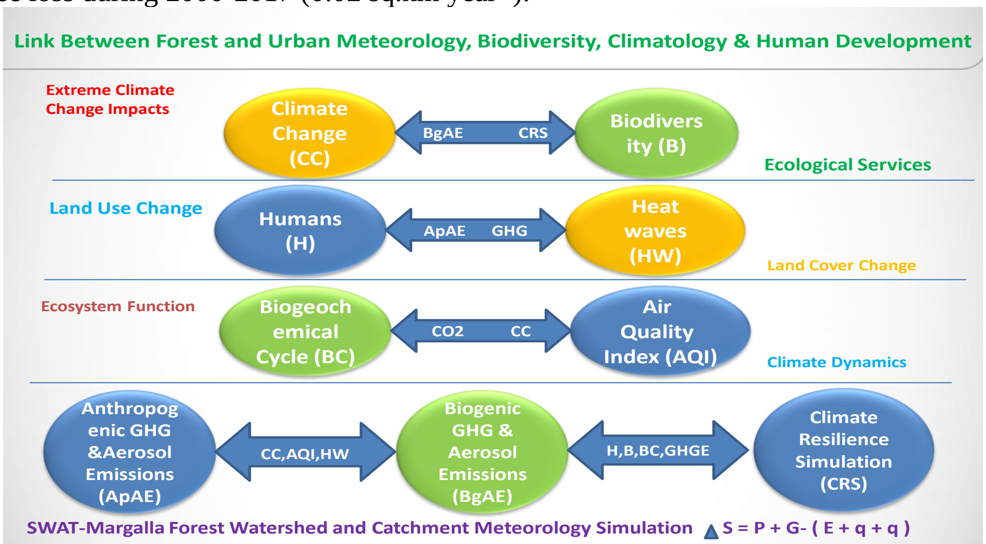


Figure 2: MF climate modelling scenario to current forest management at modified stand level CO2 emission, water resources, temperature and AQI

The intention to develop this model is to ensure environmental flows for sustainable ecosystem and improvement in livelihood opportunities and protection from climatic disaster while integrating climate change related information into the planning processes in formulating community development strategies to reduce the risk of disaster. The future scenario modelling on biodiversity and ecosystem services was prepared as case study of MF (Figure 3) to support human well-being in the city, which will defiantly become building block of reporting to policy/decision makers. It is also leading-edge knowledge of creating linkages between sustainable cities, urban green spaces, meteorology and at glance planetary health.

The data of tree cover in, tree cover gain and tree cover loss showed significant decline in annual rate of change of tree loss during 2000-2017 (0.02 sq.km $year^{-1}$).



	Tree cover in			Tree cover gain		Tree cover loss		The annual rate of change of tree loss	
Year	1976	2000	2017	1976-2000	2000-2017	1976-2000	2000-2017	1976-2000	2000-2017
Area	600 Sq. km	578 Sq. km	439 Sq. km	144 Sq. km	66 Sq. km	168 Sq. km	205 Sq. km	0.002 Sq. km/year	0.02 Sq. km/year

Figure 3: Linkage modelling of urban meteorology with forest biodiversity for assessment of HGE, CRS and human development. (Inter-link SWAT MF and MF)

3. Results

Global mean surface air-temperature shows an increasing trend over last few decades, as it is a result of human being induced changes in environment. The classification of the satellite images of non-built-up and built-up areas for two sequential instants was resulted in the formation of land use and cover of Karachi city (Figure 4). The results showed that over the period of 1984-2016, the barren land reduced, while the built-up spots had been increased significantly. The overall urban expansion of Karachi division is categorized for the years 1984 and 2016 into different legends of water, green spaces, build-up area and barren land of the city. It has been observed that Karachi division is expanding in an asymmetrical way and most of the expansion is towards West to North region.

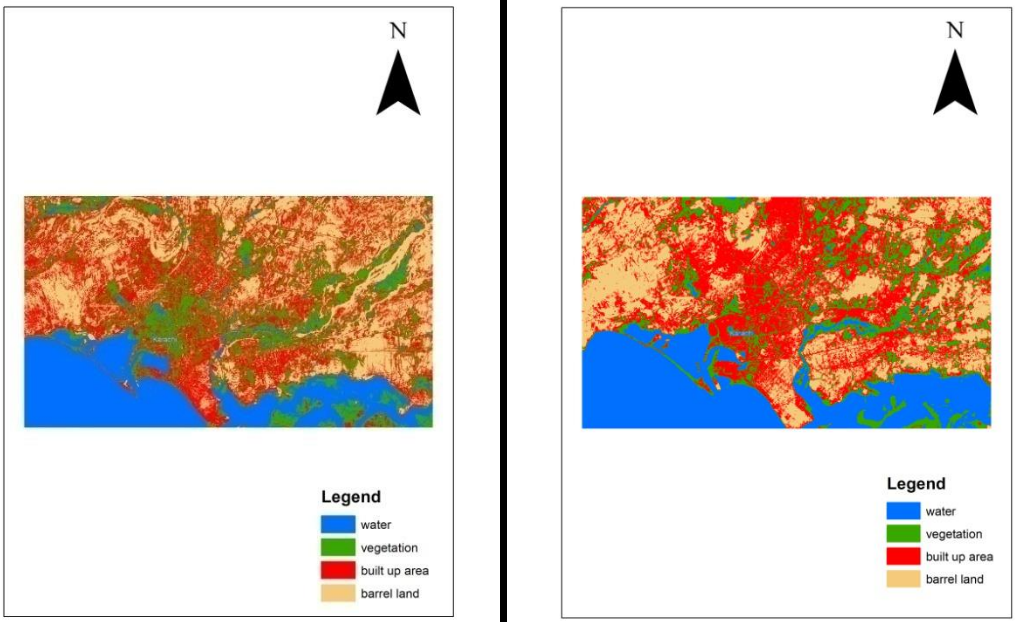


Figure 4: Urban expansion or land-cover maps of Karachi city, (a) 1984, (b) 2016 division as per supervised classifications technique

Urban expansion detection was also measured by utilizing unsupervised classification. The classification shows that the major urban growth is on North-west part towards Kemari town and Gadap town. Karachi city division is also extracted by using NDBI technique for the year 2016, and visualisation data reported that metropolitan division is expanding in an irregular manner towards West to North region. The visualization of image (Figure 4 a) showed significant green area cover in the city, and scattered build up area followed by maximum barren lands. Population during 1984 was settled in nearby towns and villages around the city that had no direct influence on city population. While on the other hand, the 2016 RS data-set indicates significant increase in urban build-up areas which automatically had reduced the urban green spaces of the city. There is significant increase in urbanization and decrease in green spaces and water bodies, which are ultimately causing serious consequences to city micro-climatic condition and promote EWEs.

The comparison of both images (Figure 4a and 4b) showed that majority of the communities migrated to the city from nearby localities which increases the barren land areas in 2016. Heatwaves hit harder to different cities in the province. Nawabshah, Thatta, and Haiderabad Kamri have observed high temperatures soaring in the past 113°F (45°C). In Nawabshah city, the recorded highest temperature was 50.2 °C in April 2018 which is the highest temperature ever recorded on earth [12,27].

3.1. Derivation of Urban Heat Island (UHI) Effect

There is reduction and slow process of evapotranspiration due to shrinking green areas and spaces in the city surroundings. With a decreased amount of vegetation, the city loses the shade, cooling effect of trees and the removal of carbon dioxide (CO_2). The principal reason for the night-time warming is the retention of short-wave solar radiation absorbed during the daytime by the building material consisting of concrete and asphalt. These materials are commonly used in urban areas for pavement and roofs that have significantly different thermal and radioactive properties compared to the surrounding rural areas.

During the interveinal of Karachi HWs, the maximum temperature map (Figure 5) of Pakistan visualized escalating temperature in the area followed by low atmospheric pressure. This causes a change in the energy balance of the metropolitan area, often leading to higher temperatures than surrounding rural areas. This energy is then slowly released during the night as a long-wave radiation, making cooling a slow process.

Because of this phenomenon, the minimum temperatures of Karachi remained extremely high during the heat-wave event.

3.2 Models' simulations

Heatwaves during the month of May for three days was calibrated by the models which resulted that inundation of CO_2 250 (S-u=1.0) stress factors with rise in temperature up to 44^0C with 70 % humidity causes more deaths in slum areas. Models projected that Mangrove Forest area has ability to absorb 55.4 million tons emissions of CO_2. Karachi. Mangrove forests (blue carbon) store more carbon than most other tropical forests, in particular, mangrove-sediment stores about five times more carbon compared to temperate, boreal and tropical terrestrial forests. According to [4,29], by 2100 if emission are not curtailed, 74% of people around the world could face deadly heatwaves and even if greenhouse gases are aggressively reduced, at least 48% of global population will face deadly heatwaves.

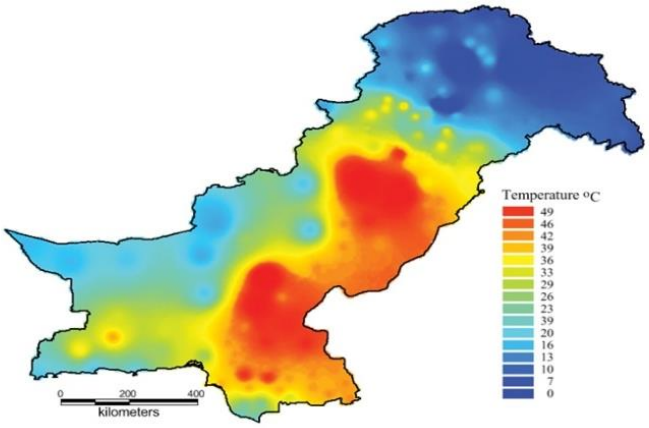


Figure 5: Mapping overview of heat waves and temperature (C) variation range impact assessment of Pakistan (Km).

According to the previous historical meteorological data simulation, the study suggested a 75 percent increase in heatwaves by 2030, 189 % by 2060 and 277 % increase by 2090. This means the country will experience around 12 ^{0}C heatwave events annually by 2030, 20 ^{0}C such events by 2060 and 26 ^{0}C events by 2090. Although Pakistan has broken Genies Book World record for Mangrove's plantation drive in 2009 and 2013. Most trees were planted in 24 hours and this is 3rd time that Pakistan has broken the record in 2018. This plantation is not enough for wildly increasing population, un-planned urbanization and deforestation. Climate scientists are agree that reducing global greenhouse gas emissions (GHG) by switching to cleaner energy sources and curbing fuel and electricity demand could help minimize global warming.

Model simulations demonstrated that rehabilitation of 30 mangrove trees per 100 m^2 might able to reduce the maximum flow of a Heat stress, tsunami, CO2, AQI by more than 90%. Inter-comparison of SILVA and SWAT Models validation skill scores showed that forest has huge potential to contribute to global efforts to reduce carbon footprints through climate smart practices of restoration, reforestation, conservation, and sustainable management of Mangrove forests. This high-carbon storage suggests that mangroves could play an important role in carbon sinks or carbon sequestration or climate mitigation.

4. Discussion

Research warns that the soaring heatwave trends may exacerbate impacts on human health, crop yields, push up irrigation needs of summer crops, increase droughts and contribute to groundwater depletion in the country. Stress in animals and increased energy demand, e.g., greater demand for air conditioning. High risk of heat stress disaster and damage to food crops and vegetation. Increased demand for water, e.g., human consumption, cooling in power stations. Infrastructure stress: buildings, roads, rail and other infrastructure. Heat waves also increase the risks for sporting and outdoor recreation activities.

The present study area has elevated baseline temperatures than that of most prior studies on extreme weather events in particular with HW. Recent higher mortality rate indicates that escalated temperatures can affect human health even in neighborhood that have adapted to extreme heat conditions. Furthermore, under climate warming, coastal cities that are presently in mid-latitudes with moderate temperatures may instigate to occurrence of more extremes heat. Our results on extreme weather conditions and mortality rate in Karachi city of Pakistan have regional and global implication for policymakers and future research work. The mounting pressure on the very limited natural resources to meet the growing needs of rapidly growing human population has been manifested as environmental deterioration locally and regionally around the planet [33]. Under recent climate conditions (1977-2005) with historical GHG concentrations [35], the ensemble average of the largest maximum daily wet-bulb temperature (TWmax) event exceeds 31°C. Maximum daily TW values, or TWmaxs, refer to the maximum temperature duration fit that human can survive, which is often set between 30°C - 35°C depending on regional differences according to various TWmaxs studies [36,37]. The present research verifies as [38] suggested limiting global temperatures to 1.5 ^{0}C above preindustrial would reduce the exposure by half relative to RCP 8.5 by the middle 21st century. However, if global temperature is exceeded 1.5 ^{0}C than substantial measure will be required to offset the large increase in exposure to severe heat waves in India. Even though the effects of El Niño and La Niña on rainfall extremities were not uniform, seasons build upon the magnitude of these incidences.

For this study, the maximum temperature record along with humidity and wind (speed & direction) data for the month of June for the normal period (1981-2010) and for the period 2015-2018 have been used to study heat wave conditions in 2015 in this sub-region (see Figure 7). According to PMD records, this severe heatwave event persisted for consecutive 5-days from 19-23 June. The daily temperature anomalies were more than 5°C for consecutive five days. The departure of maximum temperature from the normal ranged between 5.3 to 11ºC during severe heat wave (see Figure 3). Similar results of [34] also indicated that change in urban land cover size up to 50% to 100% and 100 to 150% of their present dimension. The micro-climate of 2m temperature increases by 2.8 and 1.6 degree, but the 2m precise humidity decreases by 2.2 and 1.5 g kg^{-1}, in that order. Variations in surface temperature during daytime are heater; however, 2m air temperature drop-off with maximum at night, and as metropolitan areas absorb more heat at day time and discharge at night.

Rapid urbanization and global warming have initiated UHI effect over the city as is evident from the normalized difference-built index shown in Figure 9. This research clearly indicates that, UHI would become a major health risk for the vulnerable segment of population living in mega-cities in development world such as Karachi. This research recommends the establishment of Heat-Health Warning System (HHWS) targeting the vulnerable segment of the urban centres. This warning system will have essential components of monitoring and warning service, dissemination, and communication of the heat-wave risk to the communities and enhancing their response capability to better cope with this situation.

Sustainable development cannot be achieved without significantly transforming the way we build and manage our urban spaces. As local environmental factors play a foremost role in this assessment, it is recommended that ecosystem services management in Karachi city and its surroundings be enhanced. After the onset of Monsoon rainfall, locals should be mobilizing and educate about the importance of Mangrove Forest for themselves and Karachi city. It is the time to organize mega level plantation of Mangrove plants with the participation of local community's groups, women, and youth. There is another big challenge for government is to find ways of processing and disposing of urban solid waste and garbage in Karachi. This is also one of the challenging factors during the onset of extreme weather conditions such as floods and heatwaves and is becoming root causes of planetary health issues. The health implications of these natural catastrophes endanger our health and lead to deaths if not adequately controlled. The intra comparison between Karachi and Mumbai city also showed that the status of available UGS in Karachi city are considerably less than Mumbai and other costal metropolitan cities of South Asia.

Planting trees in cities is cheap and an incredibly smart approach to improve the micro-climatic condition and human well-being. Local municipality health institutions should be investing in inner-city greenery to maintain cooler environment because green spaces regulate temperature, minimize heat island effect, water recharge and sustain well-being and air quality. The standard investment rate of trees is around one-third budget (%) of a city, which requires an annual investment, on average, of \$8 $person^{-1}$ [35,36]. The biggest risk we are facing is to ignore the need for governance based on a collective intelligence. There will be no smart city without smart citizens. Denying the risk of unrepresentative data mapping due to the lack of infrastructures and financing in poor areas would be a big mistake.

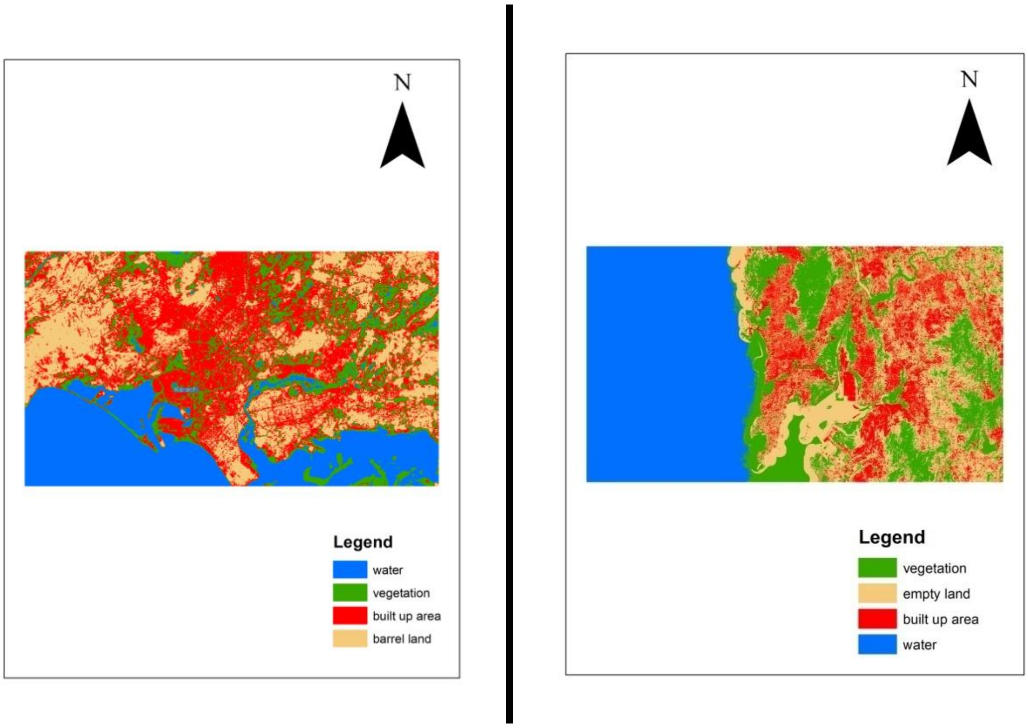


Figure 10. Real-time comparison of available urban green spaces in a) Karachi b) Mumbai along with build-up area, water bodies and barren land.

Ultimately, there should be no compromise for making sure that the smart city will contribute to the well-being and well-living of people together. To do this, urban citizens need to be empowered by entrepreneurs mastering the technical knowledge and committed towards the community. Mangrove Forests (MF) spread over 350 km (129,000 hectares) and about 129 km forest area lies in the coastal belt. Mangroves forests being destroyed in the name of development, urbanization and somehow by the locals in term of wood fuel. SILVA model simulations resulted that two third of the Karachi city CO_2 stock can be deposited by MF which contributes 19% of the Mangrove ecosystem. Model also projected that MF area has ability to absorb CO_2 emissions up to 55.4 million tons. Karachi's population will increase by 50% in the next 15 years and will reach to 24.84 million, and 42.1% of the population are estimated to be living in informal settlements. It is estimated that the annual mean air temperature (AMAT) of the city with 1 million or above inhabitants can be 1 to 3°C warmer than the temperature of its surroundings. In summer, it is observed to be little higher due to the urban-heat-island effect and extra energy consumption. Developing countries such as Pakistan needs to develop and follow the Heat Preparedness Planning (HPP) based on the WMO guidelines as heat-health action plan suggested for 18-Euroupen countries.

5. Conclusion and policy implications

SILVA model simulations resulted that two third of the Karachi CO_2 stock can be deposited by Mangrove forest which contributes 19% of the Mangrove ecosystem. Model projected that forest area has ability to absorb CO_2 emissions up to 55.4 million tons. Inter-comparison of SILVA and SWAT Models validation skill scores showed that forest has huge potential to contribute to global efforts to reduce carbon footprints through climate smart practices of restoration, reforestation, conservation, and sustainable management of Mangrove forests. SILVA estimated that forest population has excellent sink capacity to absorb maximum atmospheric carbon to combat global climate change impacts and efficiently manage REDD+ and cancontributes to improve the AQI and HW of Karachi. The project provides an assessment on changing meteorological conditions and its resultant land cover changes through a temporal GIS/RS analysis. Rehabilitation and reforestation of Mangroves Forest need to do on emergency bases with application of advance meteorological forecasting and establishment of early warning system for extreme weather events. Communities living in urban areas are vulnerable to heat waves, therefore capacity of individuals and communities may be built to respond to the heat stress during heat waves by raising heat-health awareness campaigns in the country. Moreover, green spaces may be increased by tree plantation in the city on emergency basis since green roofs are another method of decreasing the urban heat island effect. In addition, the heat island effect can be counteracted slightly by using white or reflective materials to build houses, roofs, pavements, and roads, thus increasing the overall albedo of the city.

References

[1] P.D. United Nations, Department of Economics and Social Affairs, The World 's Cities in 2018, World's Cities 2018 - Data Bookl. (ST/ESA/ SER.A/417). (2018).

[2] IPCC, Climate Change 2014 Synthesis Report Summary Chapter for Policymakers (AR5), Ipcc. (2014). doi:10.1017/CBO9781107415324.

[3] H. de Coninck, A. Revi, M. Babiker, P. Bertoldi, M. Buckeridge, A. Cartwright, W. Dong, J. Ford, S. Fuss, J.-C. Hourcade, D. Ley, R. Mechler, P. Newman, A. Revokatova, S. Schultz, L. Steg, T. Sugiyama, Strengthening and Implementing the Global Response, in: Glob. Warm. 1.5°C. An IPCC Spec. Rep. Impacts Glob. Warm. 1.5°C above Pre-Industrial Levels Relat. Glob. Greenh. Gas Emiss. Pathways, Context Strength. Glob. Response to Threat Clim. Chang., 2018.

[4] UNEP Team members, The Emissions Gap Report 2017 - A UN Environment Synthesis Report, 2017. doi:ISBN 978-92-9253-062-4.

[5] J.J. Pereira, J. Pulhin, C. Nyda, T. Dinh Trong, Appraising slow onset hazards for loss and damage: Case studies in Southeast Asia, APN Sci. Bull. (2019). doi:10.30852/sb.2019.720.

[6] A.A. Shah, R. Shaw, J. Ye, M. Abid, S.M. Amir, A.K.M. Kanak Pervez, S. Naz, Current capacities, preparedness and needs of local institutions in dealing with disaster risk reduction in Khyber Pakhtunkhwa, Pakistan, Int. J. Disaster Risk Reduct. (2019). doi:10.1016/j.ijdrr.2018.11.014.

[7] World Health Organization, Ten threats to global health in 2019, Emergencies. (2019).

[8] S. Tariq, A. Mahmood, G. Rasul, Temperature and Precipitation : GLOF Triggering Indicators in Gilgit-Baltistan , Pakistan, Pakistan J. Meteorol. (2014).

[9] O. Mazdiyasni, A. AghaKouchak, S.J. Davis, S. Madadgar, A. Mehran, E. Ragno, M. Sadegh, A. Sengupta, S. Ghosh, C.T. Dhanya, M. Niknejad, Increasing probability of mortality during Indian heat waves, Sci. Adv. (2017). doi:10.1126/sciadv.1700066.

[11] Q.I. Ahmed, H. Lu, S. Ye, Urban transportation and equity: A case study of Beijing and Karachi, Transp. Res. Part A Policy Pract. (2008). doi:10.1016/j.tra.2007.06.004.

[12] PMD, Pakistan Meteorology Department, (2018). www.pmd.edu.pk.

[13] M.A.M. and S.M. Dr. Qamar uz Zaman Chaudhry, Dr. Ghulam Rasul, Ahmad Kamal, Technical Report on Karachi Heat wave June 2015, 2015.

[14] S. Campbell, T.A. Remenyi, C.J. White, F.H. Johnston, Heatwave and health impact research: A global review, Heal. Place. (2018). doi:10.1016/j.healthplace.2018.08.017.

[15] R.M. Horton, J.S. Mankin, C. Lesk, E. Coffel, C. Raymond, A Review of Recent Advances in Research on Extreme Heat Events, Curr. Clim. Chang. Reports. (2016). doi:10.1007/s40641-016-0042-x.

[16] V. V. Kharin, F.W. Zwiers, X. Zhang, M. Wehner, Changes in temperature and precipitation extremes in the CMIP5 ensemble, Clim. Change. (2013). doi:10.1007/s10584-013-0705-8.

[17] J.J.P. Choun-Sian Lim, Making Cities Disaster Resilient in a Changing Climate: The Case of Kuala Lumpur, Malaysia, 2019. doi:DOI: · 10.24948/2019.05.

[18] IPCC, Climate Change 2014: Synthesis Report. Contribution of Working Groups I-III to the Fifth Assessment Report of the IPCC, 2014.

[19] P.K. Thornton, P.J. Ericksen, M. Herrero, A.J. Challinor, Climate variability and vulnerability to climate change: A review, Glob. Chang. Biol. (2014). doi:10.1111/gcb.12581.

[20] B. Orlowsky, S.I. Seneviratne, Global changes in extreme events: Regional and seasonal dimension, Clim. Change. (2012). doi:10.1007/s10584-011-0122-9.

[21] G. of P. Report on Climate change, Framework for Implementation of Climate Change Policy, Rep. Clim. Chang. Govt Pakistan. (2014).

[22] C. Giri, J. Long, S. Abbas, R.M. Murali, F.M. Qamer, B. Pengra, D. Thau, Distribution and dynamics of mangrove forests of South Asia, J. Environ. Manage. (2015). doi:10.1016/j.jenvman.2014.01.020.

[23] M. Rafique, A review on the status, ecological importance, vulnerabilities, and conservation strategies for the Mangrove ecosystems of Pakistan, Pakistan J. Bot. (2018).

[24] A. Sirakaya, A. Cliquet, J. Harris, Ecosystem services in cities: Towards the international legal protection of ecosystem services in urban environments, Ecosyst. Serv. (2018). doi:10.1016/j.ecoser.2017.01.001.

[25] J.L. Hatfield, J.H. Prueger, Temperature extremes: Effect on plant growth and development, Weather Clim. Extrem. (2015). doi:10.1016/j.wace.2015.08.001.

[26] IPCC, IPCC Special Report 1.5 - Summary for Policymakers, in: Glob. Warm. 1.5°C. An IPCC Spec. Rep. Impacts Glob. Warm. 1.5°C above Pre-Industrial Levels Relat. Glob. Greenh. Gas Emiss. Pathways, Context Strength. Glob. Response to Threat Clim. Chang., 2018. doi:10.1017/CBO9781107415324.

[27] WMO, World Meteorology Organization (WMO), (2018). https://public.wmo.int/en.

[28] H.C. Ho, K.K.L. Lau, C. Ren, E. Ng, Characterizing prolonged heat effects on mortality in a sub-tropical high-density city, Hong Kong, Int. J. Biometeorol. (2017). doi:10.1007/s00484-017-1383-4.

[29] S.B. Guerreiro, R.J. Dawson, C. Kilsby, E. Lewis, A. Ford, Future heat-waves, droughts and floods in 571 European cities, Environ. Res. Lett. (2018). doi:10.1088/1748-9326/aaaad3.

[30] UNEP, Emission Gap Report 2015, Unep. (2015). doi:10.1016/S0264-410X(12)01439-9.

[31] U. Ghumman, J. Horney, Characterizing the Impact of Extreme Heat on Mortality, Karachi, Pakistan, June 2015, Prehosp. Disaster Med. (2016). doi:10.1017/S1049023X16000273.

[32] D. BARTON, Synthesis Report, in: Hous. Spec. Groups, 2014. doi:10.1016/b978-0-08-021985-1.50014-x.

[33] T. Pogačar, Z. Žnidaršič, L.K. Bogataj, A.D. Flouris, K. Poulianiti, Z. Črepinšek, Heat waves occurrence and outdoor workers' self-assessment of heat stress in slovenia and greece, Int. J. Environ. Res. Public Health. (2019). doi:10.3390/ijerph16040597.

[34] B. Huang, G.H. Ni, C.S.B. Grimmond, Impacts of urban expansion on relatively smaller surrounding cities during heat waves, Atmosphere (Basel). (2019). doi:10.3390/atmos10070364.

[35] R. McDonald, L. Aljabar, C. Aubuchon, H.G. Birnbaum, C. Chandler, B. Toomey, J. Daley, W. Jimenez, E. Trieschman, J. Paque, M. Zeiper, Funding Trees for Health - An Analysis of Finance and Policy Actions to Enable Tree Planting for Public Health, 2017. doi:10.1007/s00384-008-0616-8.

[36] R.I. McDonald, Conservation for cities: How to plan and build natural infrastructure, 2015. doi:10.5822/978-1-61091-523-6.