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A Methodology to Attain Green Urban Settlements through GIS Mapping

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Abstract—*Today's fast-polluting world is posing a tremendous threat to the sustainable growth of the future generations. The swiftly expanding urban settlements, especially in the developing countries, account for a lion's share of this environmental degradation. These settlements are comprised of built environments that vary in respect of their different uses, but are similar in one aspect – all of them are non-renewable energy intensive. The energy consumption in urban settlements can be categorized in two broad divisions – (a) energy embedded in the construction material and process, and (b) energy consumed in the functioning of the building.*

At present embedded energy in buildings are being monitored through building energy rating systems, and off late the share of non-renewable energy usage in running of buildings, which is quite large, has also been an important field of research in developing countries.

However, the energy certification process of buildings doesn't take into account the positioning of building(s) within the overall fabric of the settlement. The direct result of it are severe, such as heat sinks being created in urban pockets and extremely contrasting micro-climates being created within small and medium towns.

This paper thus aims at the concept of 'Green Settlements' through energy mapping of urban settlements and its different zones and also by creating a live spatial interface by combining the common tools of GIS with the plot level energy use data. This methodology will be an effective decision making tool in spatial planning for urban settlements.

1. INTRODUCTION

The average temperature of Earth and its atmosphere has increased by an average annual value of 0.85 degree centigrade over a little above a century, precisely during 1880 till 2012. If this is alarming to the well-wishers and protagonists of the eco-system, then what frightens more is the fact that there has been a change in this average temperature of about 0.4 degrees over the last three decades, ie, 1980-2010 (IPCC, 2013). Significance of this observation – the Earth is warming up faster than it ever has, and this projects to the disturbing fact that the average temperature of the globe will increase, ceteris paribus, by 2.6 – 4.8 degrees by the year 2100. Imminent danger of this phenomenon – increase of mean sea level due to melting of ice-caps, permanent inundation of century old throbbing metropolises on the coastal lines of all the continents, increase of acidity of sea water and the fatal effect it brings to oceanic ecology, and so on.

The reason of this universal warming of the globe is green house effect of the atmosphere, caused by the Green House Gases (GHGs). These gases form a 'blanket' over the surface of the globe, thus trapping heat within it. As a 'insulator' and an indirect 'pollutant', these GHGs can be divided into two segments – (a) water vapour, (b) the LLGHGs (or long-lived green house gases). Water vapour is a natural substance, and is beyond the scope and need of human intervention. The only aspect worrying about it is that the share of water vapour may and will keep on increasing with the warming of the globe and melting of the ice-caps. The second group has GHGs that demand concern, and can be further subdivided into two segnments – (i) gases with lower GWP (or Global Warming Potential) (which are also 'short-lived' compared to the other subgroup) – includes carbon di-oxide (CO_2), methane (CH_4) and nitrous oxide (N_2O); and (ii) gases with higher GWP and longevity – includes hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluorides (SF_6). The first subgroup occurs naturally in the atmosphere, and human civilisation has increased their magnitude in the last three centuries since industrial revolution. They have a lion's share among the GHGs, accounting to 98%, and being the largest threat to ecology all eyes are set on them. However, the other sub-group claiming only 2% to them (IPCC 2013), has a more fatal implication as they have average GWPs almost thousand times that of the natural GHGs and longevity of such a period that we can deem them to be existing perpetually in the atmosphere. What more, they are created by human during the process of mechanisation, and are continuously being produced as part of day to day industrial process.

The following table 1 compares the global warming effects of these two groups of GHGs. The columns regarding the GWP over 100 years and the share of the GHGs over 200 years may be referred back to the Kyoto Protocol and the subsequent publications made by United Nations Environment Programme (UNEP 2012), whereas the third column is weighted effect calculated by the authors. From this we find that although the volumetric share of GHGs having higher

GWP is negligible, their effective warming potential is huge and in no way can we ignore them in our effort to reduce global warming.

Table 1: Greenhouse Gases and their Effect on Global Warming

Greenhouse Gas (1)	Global Warming Potential (GWP) (over 100 years) (2)	% of Total Anthropogenic GHG Emissions (2010) (3)	Weighted GWP (4) = (2) x (3)/100
Carbon dioxide (CO_2)	1	76%	0.76
Methane (CH_4)	25	16%	4
Nitrous oxide (N_2O)	298	6%	17.88
Hydrofluorocarbons (HFCs)	124-14,800 #	< 2% *	37.31
Perfluorocarbons (PFCs)	7,390-12,200 #	< 2% *	48.98
Sulphur hexafluoride (SF_6)	22,800	< 2% *	114
Nitrogen trifluoride (NF_3)	17,200	< 2% *	86

 # GWP for HFC and PFC have been assumed as the median values of given ranges.

** For the purpose of calculating weighted GWP, these GHGs have been assumed to be equitably distributed, ie, each having volumetric share of 0.5%.*

2. BUILT ENVIRONMENT AND GREEN HOUSE GASES

Building activities in modern world, especially in the urban settlements involve huge emission of GHGs. Activities like production of construction materials such as cement, steel, glass emits large amount of gases like carbon di-oxide etc, and so do the transportation of these materials to the site from the place of manufacture. It is assuring that recent activities like rating of buildings, in terms of their embedded energy as well as their energy-intensive operation, is under full swing in India and abroad through various rating systems. These systems are well established, although they take into consideration buildings individually or at most as a complex site within a city. Moreover, what is lacking is a monitor of the fluorinated gases having higher GWPs. As per the report of United Nations Climate Council (IPCC 2007): 'Refrigerants, large portion of which is used in Air Conditioning machines, emits Fluorinated gases......Among all fluorinated gas, hydrofluorocarbons (HFCs) are used in refrigerants and fire extinguishers and hence are mostly used in buildings'. The above table 1 indicates the implication of rising amount of fluorinated gases in the atmosphere and why it should now warrant our immediate attention.

2.1 The New Questions

However, there are certain questions which needs to be answered when we move from the part to the whole, ie from individual premises to neighbourhood to the city as a whole –

(a) Each building works as a heat pool. They absorb/entrap the solar radiation and then emits them through various heat exchange method. As this is attributed by the skin material of the building (e.g., brick or glass or metal cladding or something else), our first question is –
Can the heat pool effect of individual building be assessed (through a thumb rule) or monitored (on a real time data) ?

(b) What is the cumulative effect of these 'heat pools' created by these buildings and how do they contribute to the urban heat sink of that area ?

(c) Air conditioned buildings and heat sinks work in a peculiar but vicious cycle that results in constant entrapment of heat and further rise in the use of air conditioner – leading to larger emission of fluorinated gases in the atmosphere. This gives rise to the next imminent question –
How to monitor and control heat sink effect in urban neighbourhoods and how to prevent the creation of new heat sinks?

This paper thus aims at proposing a methodology to monitor and control such heat sink effects within an urban settlement. With an ever-evolving urban morphology, the process of such monitor cannot be a static system but a dynamic real time platform considering and updating its database with each and every change in the built environment.

3. THE NEW TOOL

The new method and the tool developed thereof would address the phenomenon of urban heat sink creation and their control. This section describes the step-by-step methodology:

3.1 Delineation and Study of the Urban Area

The methodology aims at controlling the development pattern through legislative frameworks, and hence each urban settlement under monitor should be considered as a composite of wards for the purpose of micro-level study and intervention.

Furthermore, the time-series nature of the method implies that it should be developed on the platform of geographical information system (GIS), thus offering scope for a multi-layered spatial analysis of the problem. The settlement under study should therefore be stratified under the following spatial delineations–

i. Administrative map showing ward boundaries;
ii. Land-use maps, at both
  a. macro-level - overall city, and
  b. micro-level - detailed building-level use study of each ward;

iii. Ground element map, which may be a hybrid satellite image, showing not only the buildings but all physical elements with their detailed attributes;
iv. Infrastructure and services map.

These maps should have to be digitized and overlaid to prepare the base map in a suitable GIS software.

3.2 Identification of Heat Sinks

Heat sinks are comprehended as urban neighbourhoods or land-use districts having a unique micro-climate that is discordant to the general climate of the city and that essentially has a higher average temperature than the surrounding neighbourhoods, especially in summer months. This part of the study analyses the available data / literature and identifies the criteria for designating an area as a heat sink.

A reconnaissance survey of the wards of the city helps a perceptual understanding of probable heat sinks, which is then confirmed by conducting detailed survey with collection of thorough environmental data (e.g., temperature, humidity, radiation etc).

Another detailed survey of the built environment in and around the heat sink regarding the construction material and their nature used in the building skins reveals their potential to trap and radiate energy to and fro the heat sink.

3.3 Preparation of Time-Series Data based on Attributes of Heat Sinks

The attributes and components of a heat sink and the buildings therein are therefore stratified into groups as follows:

i. Land-use vis-a-vis building use
ii. Material used in skin / cladding of building
iii. Structural materials and systems
iv. Ratio of built-unbuilt components – both in terms of ground coverage (two-dimensional) and massing (three-dimensional)

Another set of attributes are identified as the effect of the above groups on the Consumption, Embedding, Radiation of energy, especially in form of heat energy by the built and un-built components of the heat sink zones.

3.4 Preparation of Maps on GIS Platform

Detailed objective data on the above criteria are to be collected by exhaustive or census survey and the database prepared for the zones in suitable database software. With all these data overlaid on the base map prepared beforehand, the new map shows the identified heat sinks as well as the potential future development magnets that might become heat sink in future on a temporally 'live' spatial database on GIS platform. Preparation of this map would help analyse two things –

a. To decide what should be the optimum saturation point for a zone to come out of the situation of being a heat sink, and
b. Whether any zone has further carrying capacity (in terms of heat and energy intensive activities) to absorb more built uses in it.

3.5 Gradation of Buildings based on their Contribution in the Heat Sink

One of the basic assumption for this method is that all buildings contribute to the creation of a heat sink in a zone in varying degree. Parallel to the preparation of the GIS maps, another important step would be to sieve these buildings into grades based on their varying degree of energy intensive construction techniques and uses. This activity would be quite similar to the grading of buildings under conventional green building rating systems. This step would help in the decision making in two ways –

a. Whether a building should be allowed to introduce further heat-intensive development in it, and if yes what should be the extent of that, and
b. Whether new building/ developments should be allowed to come up in any zone, and if yes then the grade of energy intensiveness it should be allowed to be.

3.6 Preparation of Thematic Map based on Attribute Groups

The last two activities, viz, preparation of the GIS map and the gradation of building should also help the administrative authorities to monitor the concentration of energy usage in any urban zone (or ward), to ensure an equitable distribution of energy resources among various landuses and also to create and collect revenue slabs on the varying extent of energy (heat) being 'dumped' by the buildings in the urban environment.

However, such administrative intervention might bring with it great resistive reactions from the populace, which can be appeased with the help of administrative transparency. Such a candid governance can be ensure through visual representation of the analysis or reasons being shown for the administrative decisions, where the stakeholders themselves can access the database in a restricted manner to assess their situations themselves. Thematic maps generated on the GIS platform on the basis of attributes discussed above, both individually or in composite manner are the best tools to offer such transparent governance.

3.7 Development Control Enforcement and Monitoring

The thematic maps based on GIS can help in the governance of the city from the perspective of controlled development. Once such systems are developed for an entire city, they would also become an indispensable part of the urban planning exercises for future. Planning activities would not only take into consideration the carrying capacity of the city in terms of transportation and other infrastructure, but also would have to assess to what extent a zone or ward be allowed to be 'heated up'. Implementation of this methodology can be widely adopted as urban development legislations for enforcement of strict compliance while allowing a new construction.

4. CONCLUSION

This paper started with a highlight on the requirement of curbing fluorinated green house gases through controlled design and development of our built environment. We have seen for the past decade an increased awareness regarding the requirement of reducing pollution through reduction of carbon footprint and other environment friendly measures among the stakeholders of building industry. On the other hand, conservation of non-renewable energy, in most cases the process of which is non-green, has become focus for manufacturers and users of building and its component machineries. However, there is a third front where inconsiderate usage of material in architecture is leading to a constant rise in the temperature of our environment, and at the same time the increased demand for human comfort is resulting into the excessive use of fluorinate gases as refrigerants in our cooling system. This two-pronged vice now needs to be arrested, and proper planning as envisaged in this paper may lead to a better city.

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