KOM (Keep Out Mosquitoes) Project: Anthropo-philic Terraforming and Manipulation of Landscapes for Mosquito Vector Control in Malaria Disease Management and Eradication

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Abstract— **The ongoing KOM Project is researching how to construct affordable and sustainable mosquito-free zones, in malaria endemic sub-Saharan Africa and elsewhere. Mosquitoes are vectors for several diseases malaria, Chikungunya, dengue fever, lymphatic filariasis (elephantiasis), Ross River fever, West Nile virus disease and yellow fever. Isolating mosquitoes from hosts also breaks disease transmission. In summary,**

KOMKOM: Keep Out Mosquitoes = Keep Out Malaria

KIMKIM: Keep In Mosquitoes = Keep In Malaria

So, one wants to re-engineer habitations as bio-zones on the landscape scale [O(1) mile]: Mosquito-free zones (MFZ), KOM enclosures; Mosquito-confinement-containment zones (MCZ), KIM enclaves.

A KOM (KIM) enclosure is a mosquito-impenetrable wall surrounding an area, deployed permanently or seasonally in a rural or urban setting. The barrier is augmented with a distribution of BTK (bait-trap-kill) units. Mosquitoes can then be subjected to herding, destruction or entomological assessments. Currently, the Project is in the concept development stage, and is specifying and prototyping subsystems: KOM (KIM) walls, fringes: skirts and collars; BTK units; airlock technology for entry-exit ways; and automating vector destruction. The companion MedizDroids Project is researching UAVs, drones and multi-copters as mosquito control drones for vector control, that can exploited to eliminate mosquitoes from KOM (KIM) zones.

Keywords— KOM, keep out mosquitoes, environmental and habitat management, modification, manipulation, EHM, Bait-Trap-Kill (BTK), mosquito control, integrated vector management.

I. INTRODUCTION

The strategic objective of the KOM project is the specification, engineering, deployment, operation and maintenance of mosquito-free micro-zones (MFZ) suitable for the habitation of humans and their domesticated animals. The Project also supports the dual or complementary mosquito confinement micro-zones (MCZ). The overall effect is using physical means to achieve the ecological separation, isolation and segregation of humans from mosquitoes. The basic insight is that if humans and mosquitoes do not come in contact, then there will be no opportunities for mosquitoes to bite human hosts, and thus mosquitoes can be thwarted in serving as the medium of transmission of sources of disease, such as parasites and pathogens.

A deployment of KOM enclosure is achieved by constructing a physical barrier (KOM wall) that surrounds a chosen habitable area. The deployment can be permanent, semi-permanent, or temporary (seasonal). The mosquito populations within the KOM enclave are then systematically destroyed in all of the life stages: adult, larva and pupa. The techniques used [1] can be indoor residual spraying (IRS); outdoor residual spraying (ORS); larval source management (LSM) via larviciding (-LC)[2] or biological controls (-BC); environmental and habitat management, modification and manipulation (EHM*) [3]. In order to maintain, sustain and ensure that the KOM enclave remains an MFZ, it is necessary to augment the KOM wall with attached distributed collections of vector BTK (bait-trap-kill) units, deployed on both sides of the KOM wall. Depending on the attractants and semio-chemicals used in the BTK units, the KOM structures can also support the control of other disease vectors, such as black flies.

In a similar manner, a KIM enclave results when a physical barrier (KIM wall) surrounds an area, on the scale of landscapes, so that mosquito vectors cannot escape from the KIM enclave. Several actions can be taken against the mosquito populations thus confined, incarcerated or imprisoned in the KIM. The manipulations include entomological surveys and assessments; treatment with adulticides and larvicides, for vector destruction.

The KOM enclosures and KIM enclaves (K*M structures) can be deployed in several geographical settings: rural villages and communities; rural wild land; natural resource development areas (agricultural estates, farms, plantations, ranches, mining, oil, petroleum and gas exploration and extraction); and urban neighborhoods and communities. For example, one can systematically create temporary and seasonal large-scale urban KOM enclosures in the following manner: a) demarcate a KOM enclosure; b) delineate several KIM enclaves within the KOM enclosure; c) systematically destroy the vectors within the KIM enclaves, and then throughout the KOM enclosure; d) expand the KOM coverage by creating neighboring KOM MFZs, and eventually embedding KOM enclosure into increasingly larger scale KOM structures.

Other areas of potential innovation in the KOM project include the following:

- Choice of the materials for the tiles and panels used in the K*M wall construction
- Choice of landscape architectural designs that ensures that the both fringe (skirt) of a K*M wall is form fitting with the topographically uneven ground.
- Choice of materials and designs to ensure the BTK ("trap") units are affordable and sustainable.
- Choice of affordable airlock designs that provide mosquito-free entry and exit gateways, (ingresses and egresses) into KOM enclosures and KIM enclaves.
- Choice of affordable architectural designs that support the mosquito-prevention equivalents of barbed wires that top the KOM (KIM) walls.
- Using automation as much as it is feasible and affordable to accomplish the destruction of vectors in K*M zones. For example, the related MedizDroids Project [4] is currently researching the socio-technical systems and architectures that incorporate as crucial components the use of aerial platforms (UAVs, drones, multi-copters, multi-rotors, aerodynes, and aerostats), for malaria and other vector-borne diseases vector control, such as indoor residual spraying, and outdoor spraying and other treatment of vector breeding grounds and peri-domestic resting sites.
- Using as much automation as possible in the life cycle support of KOM (KIM) structures. For example, the use of robots, aerial platforms, UAVs, UAS and drones for maintenance, repair, inspection, monitoring and surveillance operations.
- Ensuring the deployment and operation of a KOM (KIM) structure for each community is affordable and sustainable.

II. Current Results & Discussion

The KOM Project is an ongoing project and is currently in the concept development stage. The current achievements include the identification and specification of the requirements for a) constructing KOM enclosures; b) KIM enclaves; c) elimination vectors from KOM enclosures and KIM enclaves.

A. *KOM Architecture*

The final KOM architecture shall consist of the following components and subsystems:

1. A wall of some empirically determined height [5], [6], [7], [8] (60ft to 75ft[1] that completely surrounds a residential or community area (such as a village and its environs) and serves as a physical barrier that cannot easily be penetrated by mosquitoes[2].
2. Such walls, exclusion fences, barriers, shall be built and interposed between peri-domestic mosquito breeding sites, and areas of human domicile or habitation.
3. The physical wall barrier will be opened at the top and not a domed enclosure.
4. The topmost fringe of the wall shall be lined with no-fly zone or no cross-over repelling subsystems that attempt to confine mosquitoes to the exterior side of the wall, so they are not able to fly or vault over the wall barrier, even if aided by wind and updrafts.[3] For eco-aesthetic reasons, that is, to minimize noise pollution, visual pollution and injury to flying wildlife, the propeller and airfoil based wind generators should be in the form of micro-fans (scale of toy fans) [9].
5. Attractor traps and mosquito collection and disposal units are liberally arranged on both sides of the wall, as can be afforded, to gather and ultimately destroy the mosquitoes that attempt to cross the barrier. Therefore, a height based physical barrier design must be supplemented and supported by other means of keeping out ALL mosquitoes outside a KOM enclosure.
6. Specialized sub-structures to ensure that several points of vulnerability do not compromise the barrier's functionality: supporting the ground-to-wall fringe interface; tunnels dug by animals; gateways, egresses and ingresses into the enclave.
7. Integration with strategies for elimination of mosquito vectors within KOM enclosures.

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[1] According to the American Mosquito Control Association (ACMA), the flying height depends on the mosquito species, and tops out at about 25ft to 30ft, (7.62m to 9.14m). However, the published literature also reveals mosquitoes being caught in traps 50ft (15.24m) off the ground [23], and there at least one Aedes species that flies at 65ft (20m) in the branches of trees, and feeds on monkeys, if it cannot find human hosts (Jones 2012). No one has yet documented empirically how mosquito flying behavior will change, when height-based physical barriers are imposed between mosquitoes avid for blood meals, and their access to these resources have been thwarted.

[2] Wind speed increases with height from the ground (Earth's surface), and at around 25ft to 30ft roughly becomes equal to mosquito flight speeds. Thus, above 30ft, a mosquito is no longer in control of its flight and can only be swept along by the wind currents.

[3] It has been documented by others that mosquitoes, being weak fliers dislike flying in gusts or breezes, (local winds of speeds greater than 10 mph) [10], [11]. According to Dr. Chulder of Washington University, mosquitoes "seem to avoid wind speeds that approach their own flying speeds of 0.9 mph to 3.6 mph (0.4 m/sec to 1.6 m/sec)".

The ideal KOM architecture based solely on physical barriers has to be a domed village, domed town (or even a domed city or domed section of a city), where the whole residential space is fully enclosed or enwrapped. Nevertheless, the engineering challenges and obstacles that must be faced to construct a dome over even a village of a few huts and houses renders the domed approach unrealistic and impractical. Thus, of practical necessity, KOM designs are "open roof" walled enclosures.

It should also be clear that even if wildly successful, repulsion based augmentation to the barrier is not enough. What happens to the mosquitoes that were passively stopped or deterred by the physical barrier or which survive the repulsion subsystem? They will continue to exist to try and try again to cross-over. Therefore, the KOM design has to be augmented with subsystems capable of attracting individual or swarms of mosquitoes, trapping or confining them, and disposing of them, that is, Bait-Trap-Kill (BTK) units.

A plausible design is that the physical barrier, should be liberally studded with mosquito attractor pockets, serving as baits and traps. Most of these attractor gateway traps should be located at lower heights of the KOM barrier. The attractors should also be placed on both sides of the barrier. On the inside wall portion, the attractor should be designed to use attractants, pheromones and other semio-chemicals, formulated to be so irresistible that the mosquitoes will be enticed to land and be lured to enter such traps, instead of flying off into the interior of the KOM enclave, in search of human hosts.

Existing product mosquito trapping ideas that can be refined and re-scaled for use in developing countries include CO2–attractant based traps and light traps. To dispose of the trapped mosquitoes, they can either be killed by using chemicals, heat, or desiccation, if confined at least for 10 to 15 days, when the malaria parasites would have matured in the mosquitoes, but would have no opportunity to be transmitted to human hosts and infect them. A solar BTK sub-project is currently in the stage of specifying, integrating and prototyping the affordable and sustainable versions of the various subcomponents for baiting, trapping and killing.

B. KIM Architecture

A KOM design builds an enclave architecture that attempts to exclude mosquitoes from the interior of the enclave. A KIM architecture is a dual structure. It attempts build an enclave that keeps mosquitoes confined within it. Thus, in a KOM object, the goal is that mosquitoes outside the enclave cannot enter it, but in contrast in a KIM entity, mosquitoes are confined inside the enclave, and thus cannot exit out of it. An interesting aspect of KIM designs is that they do not have to be fully closed enclaves, unlike KOM structures, where closure or circumvallation is a fundamental requirement.

In some cases, the same barrier wall will serve as the common boundary for a KOM and a KIM enclave. In other cases, a "No Man's Land" or "DMZ" can separate the neighboring KOM and KIM wall barriers. An interesting useful variant of the architecture is to have temporary or transient KIM enclosures, isolated and embedded in a KOM enclave, at least until all the mosquitoes in such a KIM enclosure have been eliminated. Then the KIM zone can be re-absorbed into the KOM enclave.

There are other areas of vulnerability of the physical barrier wall. The architecture should ensure that the contact between the ground surface, (which will not be smooth), should be tight-fitting with the ground facing fringe (skirt) of the barrier wall. A cheap solution is to use sandbags or waterproof seed bags, as the interface between wall skirt and the ground. A more effective solution will be to use assembled deformable, inflatable tubes and tubular sections (possibly made of geomembranes or other geosynthetics) that can be filled with water, sand or seeds. The wall's skirt can also be liberally studded with attractor traps. The potential also exist for rats, rodents and other hole-digging animals to construct underground tunnels that compromise the integrity of the barrier walls, and this has to be taken care of.

Several gateways and doorways need to be constructed for both humans, domesticated animals and road vehicles to enter and exit a KOM enclave. The architectural design and engineering has to ensure that these ingresses and egresses do not become highways for mosquito travel into the KOM enclave. A plausible design to address this issue is that each intentional breach in the barrier wall is constructed as an **airlock** like chamber or mini-tunnel. The key idea is that the two gateways are the end of the chamber should not be opened simultaneously. All vehicles will be required to slowly move through such chamber-tunnels (chunnels), much as is currently done at toll-crossings and border crossings. Each chamber will be overlaid with multiple layers (a sandwich) of attractors, repellents and insecticides, (compare a sequence of bead-curtains in doorways). Thus, mosquitoes that attempt to enter the enclave through this route will have to "run the gantlet (gauntlet)", with the strategic goal that all of them will either be killed or trapped by the time they reach the end of the chunnel.

In some manner, the KOM (KIM) designs can be seen as the beginning of the "domestication" and "herding" of mosquitoes, which is probably the only viable strategy for eventually eradicating malaria, because the mosquito vector can be transformed or subject to anthropo-philic "terraforming" or manipulation.

C. Materials for KOM and KIM Walls

What Materials can be used to construct the KOM and KIM Physical Barriers? Some options can be immediately eliminated, primarily based on cost considerations and difficulties of maintainability. These include candidates such as metal plates and tiles; metal mesh; tiles made from ceramics, clay, cement, plaster, plaster of Paris, glass, stone and rubber. The most suitable materials are likely to be blocks of fabric (cloth or textiles, compare quilts), or plastics (compare curtains, draperies) that are assembled together using plastic zippers. An alternative class will be sheets, films, membranes made from plastics (transparent or clear vs. non-transparent or opaque) (compare shower curtains). The assemblies can be geodesic constructions, quilts or tessellations of e.g., 10ft x 10ft tiles.

The materials used must be durable in the sense of being able to withstand tropical and sub-tropic climate and weather conditions.

An intriguing architecture is to use insecticide treated (coated) meshes, tiles and quilts, (made of fabric, woven plastics, polymers), to build KOM (KIM) walls. This will amount to using ITN-like structures on larger geographical scales than bed-net form factors [21]. Further research is needed to determine if such meso-scale use of insecticide treatment of materials technology is cost-effective.

D. KOM to KIM Inter-conversion

There is an interesting algorithm for using the KOM (KIM) structures for effective and systematic malaria mosquito vector suppression in urban settings. It proceeds as follows:

1. Given an urban area, tessellate it into parcels, plots, zones, cells or compartments, much like the zones created for wireless frequency allocation for mobile and cellular phone communications.
2. Choose an initial number of the zones, and construct temporary or transient KIM structures enclosing them.
3. For each KIM zone, search, find and destroy all mosquitoes in all life stages: eggs, larvae, pupae and adults.
4. Once KIM zone is declared, verified and certified to be mosquito-free, construct a temporary KOM structure encircling the KIM enclave. Then tear down the circumvallated KIM structure, so that the zone is now a mosquito-free KOM zone.
5. Repeat the above process until all the zones in the area have been converted into KOM zones.
6. For aesthetic reasons the KOM barrier walls on the outskirts (perimeter) of the urban area, can be left standing, but most, if not all of the walls of the internal zones can be "dissolved", so that the whole urban setting become one giant KOM mega-zone.

It plausible that the most viable KOM (KIM) architectures in urban settings will typically be ephemeral or transient structures, much like perennial plants.

E. Comparative Cost Analysis

The costing analysis conducted so far indicates that proven and operational KOM deployments will be more cost-effective than existing approaches to mosquito integrated vector management and control (IVM/IVC), in support of malaria integrated disease management (IDM). This still the case even is KOM deployments are used to supplement existing practices. Current and conventional malaria IDM includes the following recommended practices, each of which contributes to overall costs:

a) Malaria case management (rapid diagnosis and treatment, such as WHO's recommended test, treat and track (T3) strategy) (MCM);
b) Use of artemisinin-based combination therapy (ACT)
c) Use of Long-Lasting Insecticide Treated Nets (LLIN) and Insecticide Treated Nets (ITN) (LLIN-ITN)
d) Intermittent Preventive Treatment in Pregnancy (IPTp)
e) Personal Protection Management, using repellents (PPM)
f) Education, Communication, Counselling, Engagement (ECE)
g) Insecticide Resistance Management (IRM)
h) Indoor Residual Spraying (IRS)
i) Outdoor Residual Spraying, of peri-domestic sites (ORS)
j) Ultra-Low Volume/Space Spraying Management (ULV-SSM)
k) Larval Source Management/Larviciding Control Management (LSM-LCM)
l) Larval Source Management/Biological Control Management (LSM-BCM)
m) Environmental and Habitat Modification and Manipulation/ Small Scale (domestic and peri-domestic) Environment (EHM*-SSE)
n) Environmental and Habitat Modification and Manipulation/ Large Scale Environment (EHM*-LSE)
o) Malaria IDM and Mosquito IVM/IVC (Malaria & Mosquito Management) Operations Administration and Management (MMM-OAM)

In comparing conventional Malaria IDM and KOM-based deployments, one can assume that the following practices, and hence their costs, will remain the same in both cases: MCM, ACT, LLIN-ITN, IPTp, PPM, ECE, LSM-LCM, LSM-BCM, EHM*-LSE and MMM-OAM. The most and considerably significant costs in this group are contributed by ACT, LLIN-ITN, ECE and MMM-OAM, each being correlated with housing density, coverage area and human population count of the target area, zone or region. Thus, the cost comparisons in the model can be summarized as follows, (see Fig.1 for the details of derivation):

$$Cost\ of\ Conventional\ MMM(MMM) = Cost(IRS.MMM) + Cost(ORS.MMM) + Cost(EHM.SSE.MMM) \quad (1)$$

$$Cost\ of\ KOM\ based\ MMM(KOM) = Cost\ of\ KOM\ OAM(KOM) + Cost(IRS.KOM) + Cost(ORS.KOM) + Cost(EHM.SSE.KOM) \quad (2)$$

The remaining practices in conventional Malaria IDM that contribute to the costs are: IRS, ORS, ULV-SSM and EHM*-SSE. The duration of the interval between LLIN/ITN net re-treatment (3 years to 5 years) can be used as the time horizon for cost calculations.

Let L (linear dimension) represent the spatial length scale of the target geographical area. Then Area dependent variables vary as $[L^2]$. In particular, both $Cost(IRS)$ and $Cost(ORS)$ vary as $[L^4]$, and $Cost(EHM.SSE)$ varies as $[L^2]$. The Mosquito IVM/IVC practices that will be associated with a KOM deployment are IRS, ORS and EHM*-SSE that are required to clear KOM enclosures, in order to transform them into mosquito-free zones (MFZ). The major impact should be that for each IVM/IVC sub-practice, the frequency of application or visit sessions to support KOM should be reduced significantly, for example by 80%. There an additional cost component associated with the initial deployment and operation of a KOM enclosure, $Cost\ of\ KOM\ OAM(KOM)$.

Hence, $Cost\ of\ KOM(KOM)$ varies as $[L]$, because its significant aspects and roles such as the material usage and mosquito trap (bait-trap-kill, BTK) coverage of KOM is dependent on the perimeter (or circumference) of the target geographical area.

Thus, due to the differences in $[L]$, $[L^2]$ and $[L^4]$ dependencies and reductions in the frequencies of applications, for most realistic cases and scenarios, such as coverage of areas with 1 mile or more radius, KOM deployments are expected to reduce the costs of Mosquito IVM/IVC in suitably chosen time horizons.

The KOM Project research group is currently in discussions with the New York City government to deploy and test the KOM technology and underlying model in the local ponds and marshes located near the researchers' urban university, as a case study.

III. Future Research and Future Work

The future research stages of the KOM Project include: a) Engineering, specification, modeling and simulation of the component subsystem (walls tiles, panels, sections, poles, bottom fringe skirts, top fringe necklaces, BTK units); b) Football field or soccer field scale demonstration and assessment; c) Urban and peri-urban pilot deployments, as well as rural pilot deployments, both in N. America and sub-Saharan Africa; d) Widespread global deployment of KOM structures. There several other ancillary questions that also need to be answered in the engineering, design, development and deployment of an operational KOM (KIM) architecture. Is it Affordable? Is it Sustainable? How does the KOM (KIM) approach fit into Malaria Integrated Disease Management? What are the potential Ecological and Environment Impacts, especially on other species?

The primary results of the KOM Project will be the engineering specification of KOM architectures and deployment tactics for the successful creation of expanding local MFZs and MCZs. The Project results will be assessed by the impacts KOM deployments have on malaria disease transmission and morbidity.

IV. Related Work

The KOM Project properly belongs to the environmental management approach to integrated vector management. Environmental management consists of environment and habitat modification and manipulation (EHM*), [1], [3]. The EHM* was prevalent in the early part of the twentieth century, but was supplanted by the chemical means of mosquito vector control, relying on insecticides (adulticides and larvicides). Concerns and challenges of mosquito insecticide resistance will likely propel EHM* again to the forefront of integrated vector management [11] in the new century.

Bauer and Skovmand obtained a patent on using insecticide treated nets to build exclusion fences for control pests in agriculture [13]. Meadow and Johansen have built exclusion fences up to a height of 13ft (4m), against Brassica root flies (*Delia radicum* and *Delia floralis*) [14]. Brown describes the use of exclusion fences in Nicosia, Cyprus, to defend against locust plagues [15].

A fairly extensive literature search reveals only the use of light barriers as walls to protect (sub-village) premises from mosquitoes. The two main ideas are the Photo Fence from Intellectual Ventures [16], [17], demo'ed in 2010; and ongoing research at Columbia University by Dr. Szabolcs Marka, who has discovered that infra-red (laser) light seem to act as a wall barrier or optical shield that mosquitoes are reluctant to cross [18], [19]. The Photonic Fence is a laser based system capable of recognizing and distinguishing female mosquitoes from other flying insects, and then killing the mosquitoes with powerful lasers, as the mosquitoes attempt to cross a light barrier. Dr. Szabolcs Marka and co-workers have discovered that mosquitoes are reluctant to cross infra-red laser beams. The reasons for this reluctance are currently being researched with a US $1 million grant from the Bill and Melinda Gates Foundation.

V. Summary & Conclusions

The fundamental insight of the KOM project is that if one can successfully segregate, separate, isolate or physically keep humans and mosquitoes apart from each other, this will significantly aid all efforts of malaria control. Inherent in the notion of success of the deployment of such physical barriers are the attributes of functionality, feasibility, affordability, and sustainability. To achieve such human-mosquito segregation, the KOM project advocates the creation of two types of bio-zones: a) mosquito-free zones (MFZ), serving as disease-free, worry-free and pest nuisance-free havens for humans; and b) mosquito confinement or containment zones (MCZ), from which mosquito populations and swarms are prevented from leaving, when such places have served as breeding sites or resting sites. MFZs can be established as KOM enclaves, using exclusion walls; and MCZs can be constructed as KIM enclosures and wall barriers. The KOM (KOM) architectures are deployable in both urban and rural environments to reduce or minimize the contact and encounters between humans and mosquitoes.

When the KOM innovation is proven successful and practical, it will make significant contributions to global health integrated disease management, via mosquito vector control. For malaria disease management, the KOM deployments will support not just malaria control, but can be used to make significant progress towards malaria suppression, reduction, mitigation, elimination and eventual eradication [20], [22].

REFERENCES

[1] J. A. Rozendaal, Vector Control: Methods for use by Individuals and Communities, 1997.

[2] World Health Organization, The Role of Larviciding for Malaria Control in sub-Saharan Africa. Geneva: World Health Organization. 2012

[3] World Health Organization. Manual on Environmental Management for Mosquito Control with Special Emphasis on Malaria Vectors. Geneva: World Health Organization. 1982.

[4] J.-T. Amenyo, "MedizDroids Project, " IEEE GHTC 2014. 2014, (in press).

[5] R. Bellini, R. Veronesi, S. Draghetti and M. Carrieri, "Study on the Flying Height of Aedus caspius and Culex pipiens Females in the Po Delta Area, Italy," Journal of the American Mosquito Control Association. Vol. 13, pp. 356-360, 1997.

[6] W. L. Bidlingmayer, "Mosquito Flight Paths in Relation to Environmental Effects of Vertical and Horizontal Visual Barriers," Annals of the Entomological Society of America. 68:1, pp. 51 – 57, 1975.

[7] M. T. Gillies and T. J. Wilkes, "Vertical Distribution of some W. African Mosquitoes (*Diptera Culicidae*) over Open Farmland in a Freshwater Area of the Gambia," Bulletin of Entomological Research. vol. 60, issue 01, pp.5-15, 1976.

[8] M. T. Gillies and T. J. Wilkes, T.J., "The Effect of High Fences on the Dispersal of some W. African Mosquitoes (*Diptera: Culicidae*). Bulletin of Entomological Research. vol. 68, issue 03, pp. 401-408, 1978.

[9] P. D. Gammack et al., "Bladeless fan assembly." U.S. Patent Application 20090060711A1. March 5, 2009.

[10] E. J. Hoffman and J. R. Miller, "Reassessment of the Role and Utility of Wind in Suppression of Mosquito (*Diptera Culicidae*) Host Finding: Stimulus Dilution Supported Over Flight Limitation," Journal of Medical Entomology. vol. 40, issue 5, pp. 607 – 614, 2003.

[11] C. Garrett-Jones, "A Dispersion of Mosquitoes by Wind" Nature. vol. 4190:, pp. 285ff., 1950.

[12] World Health Organization, Handbook for Integrated Vector Management. Geneva: World Health Organization. 2012.

[13] B. Bauer and O. Skovmand, O., "Agricultural Fencing," WIPO Patent WO 03/003827 A1. 2003.

[14] R. Meadow and T.J. Johansen, T.J., "Exclusion Fences against Brassic Root Flies (Delia radicum and D. floralis)," IOBC/wprs Bulletin vol. 28, pp. 39-43, 2005.

[15] S. Brown, The Locust War In Cyprus, 1923.

[16] J. Kane, J., "Photonic Fence," IEEE Spectrum, April 30, 2010.

[17] R. A. Hyde, E. Johanson, J. T. Kane, N. P. Myhrvold, N. J. Nugent, N. R. Peterson and L. L. Wood, "Photonic Fence," US Patent. US 2010/0186284 A1. 2010.

[18] K. A. Dolan, "Using a Light Barrier to Repel Mosquitoes," Forbes, Nov. 2011.

[19] S. Marka, Z. Marka and I. Bartos, "Optical Barrier to Pests," US Patent Application. US 20120032096. 2012.

[20] N. Becker, D. Petric, M. Zgomba , C. Boase, M. Madon, C. Dahl and A. Kaiser, Mosquitoes and their Control. Berlin: Springer, 2010.

[21] R. Faiman and A. Warburg, "Insecticide Treated Vertical Mesh Barriers Reduced the Number of Biting Mosquitoes," Medical and Veterinary Entomology. vol. 26, issue 1, pp. 26 – 32, 2012.

[22] J. D. Sachs and R.G. Chambers, "The new global war on malaria. Realizing the right to health," vol. 3, 305-320, 2009.

[23] W. E. Snow, W.E. and T.J. Wilkes, "The Vertical Distribution and Age of Mosquito Populations in W. Africa Savannah," Transactions Royal Society of Tropical Medicine and Hygiene. vol. 66:, pp. 536, 1972.

a)

Cost(IRS) = Frequency of Application(IRS) * Cost per Visit Session (IRS)

Cost per Visit Session(IRS) = Number of Houses * Cost per Visit Session per House(IRS)

Number of Houses = Housing density * Housing Area

Cost per Visit Session per House(IRS) = House Area * Unit Cost Per House Area(IRS)

b)

Cost(ORS) = Frequency of Application(ORS) * Cost per Visit Session(ORS)

Cost per Session(ORS) = Number of Houses * Cost per Session per House(ORS)

Number of Houses = Housing density * Housing Area

Cost per Session per House(ORS) = House peri-domestic Area * Unit Cost Per House Area(ORS)

c)

Cost(EHM.SSE) = Frequency of Application * Cost per Visit Session(EHM.SSE)

Cost per Visit Session(EHM.SSE) = Housing Area * Unit Cost Per Area (EHM.SSE)

d)

Cost of KOM OAM(KOM) = Cost of KOM Initial deployment(KOM) + Cost of KOM Maintenance & Repair Operations (KOM)

Fig. 1. KOM Cost Analysis Model