The Use of Multispectral (MSS) and Synthetic Aperture Radar (SAR) Microwave Remote Sensing Data to Study Environment Variables, Land Use / Land Cover Changes, and Recurrent Weather Condition for Forecast Malaria: A Systematic Review

M. Palaniyandi1,*, P. Manivel2, T.Sharmila2, P.Thirumalai2

1ICMR-Vector Control Research Centre, ICMR-VCRC Field Station, Madurai-625002, Tamil Nadu, India
2PG and Research Department of Geography, Government Arts College (Autonomous), Kumbakonam, (Affiliated to Bharathidasan University), Tamil Nadu, India
*Corresponding author: smp.geog@gmail.com

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Abstract Malaria is endemic problem in the low and middle income countries, especially, sub-Saharan Africa, is caused by Plasmodium falciparum contributed on the major parts, and Plasmodium vivax parasites in the minor parts claim for millions of morbidity and mortality on the global level. Mainly due to the climate change, monsoon failure, declining agriculture crop production, population movements on poverty, mushroom growth of unplanned urbanization, landscape and land cover changes. Multispectral (MSS) satellite data and Synthetic Aperture Radar (SAR) imagery has been used for the replacement of conventional survey methods for the assessment of the problems. Remote sensing of environmental information has been used to study the variations of climate conditions; land use/ land cover changes and its impact on natural environmental transitions, assess breeding potentiality, and forecast malaria for the past 4 decades. It provides the reliable, picturesque, repetitive, precise, speed, and low cost comparatively. Remote sensing technology has been applied as alternative tool, a scientific method to develop spatial models for forecast malaria for larger areas; regional, national, and global scale. Malaria is prolonged public health challenging problem in Africa continent, tropical countries, and sub-tropical regions for several decades, it claims 2 million death tolls every year, especially, in the sub-Saharan Africa regions excessively tremendous problem, despite, all kinds control measures. The perceptions of spatial model for malaria prediction/ forecast malaria epidemics have been attracted by many researchers for past 4 decades. Therefore, present study is aimed to review relevant studies of the use of multispectral satellite data, and synthetic aperture radar imagery to analyze recurrent weather environment (temperature, precipitation, relative humidity, and saturation deficiency), land surface temperature (LST), sea surface temperature (SST), vector breeding potentiality, deforestation; land use/ land cover changes for forecast malaria.

Keywords: Tropical infectious disease, Plasmodium falciparum, Plasmodium vivax, climate determinants, multispectral satellite (MSS) data, synthetic aperture radar (SAR), microwave remote sensing, land use, / land cover changes, forecast malaria, Remote Sensing and GIS

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1. Introduction

Tropical and sub-tropical world has rigorously been affected by the vector borne infectious diseases throughout the historical records [1], particularly, malaria epidemics on the consequences of natural and manmade environmental transition, land use / land cover changes, and recurrent weather condition [2-16]. Malaria epidemic has been declined throughout the tropical regions in Sub-Saharan Africa, South America, South-East Asia including India for several decades [1,17], however, malaria is major problem in Sub-Saharan Africa nations, and other third world countries [1], despite, use of mosquito bed nets, and other prevention measures added much awareness among the communities [1]. The purpose of this study to reveal the major determinants of regular malaria outbreaks or endemic situation in the regions including the agricultural land use, a permanent /
intermittent of water logging land covers, seasonal migrations/movements to both rural and urban for livelihood. Present review works, mainly focus on forecast malaria early in advance and management of the epidemic situation in the endemic regions for sustainable health, particularly, in the third world Africa nations, and other tropical countries. Both endemic and epidemics spread into newer areas determined by the complex of phenomenon including changes in environmental features, socio-economic vulnerability, climate determinants, physiographic landscapes, etc., however, the environmental transitions caused by land use/land cover changes[3,4], and weather conditions [5,6,7] are playing important role in the changing scenario of endemic and epidemic diffusion. Multispectral (MSS) satellite electromagnetic spectrum data with different ranges of spatial and temporal resolutions pertaining to land use/land cover changes, determine the land resources in the regions, and synthetic aperture radar (SAR) imagery provides the weather data [10-16].

Remote sensing and GIS has been used to survey, determine vector breeding potentiality, vector surveillance, and forecast vector borne disease epidemics for the past 4 decades [9-16]. The objective of present study, review the available source of remote sensing data and its application to public, health medical entomology, with keen interest in malaria control and management. Satellite data could provide the information on a range of spectrums, band width, efficacy of onboard sensors of the available land resource satellites, and meteorological satellites, which has facilitate to study land and water resources, and to calculate accurate atmospheric weather condition [9-16].

Earth orbiting land resource satellites imagery for mapping environmental variables: Vectors prevalence is definitely controlled by the environmental variables, viz., landscape topography, altitude, slope, soil types, soil moisture, vegetation, lakes, rivers, canals, streams, ponds, pools, dams, agriculture practice, domestic animals, human populations, settlement types and patterns, etc., [18] Malaria is classified into four types based on the environmental features and phenomenon, such as; i) Highland malaria, ii) Lowland/plain malaria, iii) Urban malaria, and iv) Coastal malaria. Multispectral satellite data were used to study the environmental variables for the past several decades [1-18]. The remote sensing data has been used to obtain information relevant to the environmental features for mapping each and every variable accurately, and study the distinctive nature of temporal characteristic and spatial pattern of environmental risk factors dynamic phenomenon. Mostly, the confirmed malaria epidemic cases are registered in the highlands extensively [6,12], and moderately in the other environment because of the unlikelihood of environmental features and climate variations are unstable, including the Indian sub-continent [6,12]. It doesn’t mean that we are blaming the environmental variables, and climate parameters for the malaria epidemics, but, at the same time, it can be changed the situation radically, and therefore, a time series model could be served the purpose to monitor environmental changes and climate as well. Definitely, large scale environmental transitions, land use/land cover changes, recurrent weather conditions, and manmade developmental activities such as; mega water resource projects, urban development, increasing industries and factories, change in agriculture practice (from dry land agriculture to wetland irrigation agriculture), and floating population movements for occupation are playing important role in the human host-parasite-vector interaction, development of parasites, mosquito vector fecundity, sustain or promote malaria epidemics spatial diffusion, shifting of epidemic transmission, and decline or increase of infections state in the community. The study revealed that developmental activities are altered the natural environment in short duration and has effect on the human-host-vector-pathogen interaction, and the consequences, the epidemiology of mosquito borne malaria epidemic scenarios have been changed accordingly. Generally, the tropical and sub-tropical regions have the suitable environment, climate conditions, shifting of agriculture practice, etc., are fueling for the vector-parasites thrive [3,6,9,16]. Researchers have been choosing the available remote sensing data for the study of malaria epidemic disease risk factors and ranked them to mapping risk prone areas, and to make a continues surveillance in the endemic region.

| Name of the Satellite, & Name of the Country | Camera/ Sensors | Band width & Efficiency of the Satellite | Spatial Resolutions | Repetition & Swath width | Utility of the Remote Sensing data/ Earth Resource Satellite Data Applications | Potential use of satellite data application to VBD Ecology & Control |
|---|---|---|---|---|---|---|
| Landsat 1-3 | Optical sensor | MSS Band width Green (0.52-0.60 μm) Red(0.63-0.69 μm) | Landsat 1-3 68 X 83 meters | Landsat 1-3 18 days | Mapping Land Use / Land Cover- Level 1,2,3,4 | Monitoring Land use / Land Cover Changes |
| Landsat TM 4-9 Thematic Mapper (TM) | Landsat-3 RBV and MSS | MSS Band width TM 7 Bands | Landsat-7 a panchromatic band with 15m spatial resolution | Landsat 4-9 16 days | Monitoring urban sprawl, urban developments |
| Launched by USA (NASA / USGS) | RBV- Return-Beam Vidicon | Band 1-4, 0.45 μm-0.52 μm 0.52 μm-0.60 μm 0.63 μm -0.69 μm 0.76 μm -0.90 μm 1.55 μm -1.75 μm | TM 4-9 30m, 15m 100m, spatial | 185 Km 30m spatial resolution | Urban Environmental Transitions |
| | TM, MSS, RCA | Band 5, Infra Red | | | Mapping and monitoring water pollution & water quality | Mapping and monitoring water resource & water pollution|
| Name of the Satellite, & Name of the Country | Camera/ Sensors | Band width & Efficiency of the Satellite | Spatial Resolutions | Repetition & Swath width | Utility of the Remote Sensing data/ Earth Resource Satellite Data Applications | Potential use of satellite data application to VBD Ecology & Control |
|---------------------------------------------|-----------------|----------------------------------------|---------------------|-------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Resourcesat1,2, Cartosat2, Cartosat3, USGS (USA (NASA / ISRO)) | RCA-one broad spectral band (green to near-infrared: 0.505 µm –0.750 µm) AVHRR - (Advanced Very High Resolution Radiometer) AVHRR 1-2 5 Channels AVHRR 3.1-3A,3B, 4 and 5 | 1.55 µm -1.75 µm Band 6-7, TIR 10.41 µm -12.5 µm 2.08 µm -2.35 µm | resolution 30 meters (visible, NIR, SWIR); Band 5 IR, 120m spatial resolution | 1.1 Km 1-2 Days 2500 Km | Crop production estimates Assessing and monitoring health of coastal ecosystems, grass and forest fires Mapping Vector Ecology | Mapping Vector Ecology VBD Epidemic Risk Assessment Mapping epidemic hotspots, and spatial prediction of VBD |
| NOAA satellites (National Oceanic and Atmospheric Administration) | AVHRR - (Advanced Very High Resolution Radiometer) AVHRR 1-2 5 Channels AVHRR 3.1-3A,3B, 4 and 5 | Visible to Thermal Infrared 0.58 µm -0.68 µm 0.725 µm -1.0 µm 1.58 µm -1.64 µm 3.55 µm -3.93 µm 10.3 µm -11.3 µm 11.5 µm -12.5 µm | 1.1 Km | | Meteorological applications (weather forecasting) Day and Night Clouds LST-Land surface temperature, SST-Sea surface temperature | A comparative study and spatial auto correlation between LST /SST and Vector Ecology & Epidemic Transmission |
| MODIS / TERRA (Moderate-Resolution Imaging Spectro Radiometer) | MODIS / TERRA (Moderate-Resolution Imaging Spectro Radiometer) USA (NASA / USGS) | 36 Channels Radiometric data acquisition | Visible to Thermal Infrared | Band 1-2, 250m Band4-7, 500m Band 8-36, 1000m | 1-2 Days 2330Km | Atmospheric, oceanic, land surface, Land surface temperature/emissivity and cryospheric features (sea ice, lake ice, river ice, snow cover, glaciers, ice caps, ice sheets, and frozen ground) | A comparative study and spatial auto correlation between LST /SST and Vector Ecology & Epidemic Transmission Epidemic Risk Assessment |
| IRS series (Indian Remote Sensing Satellites) | Optical sensor, etc., IRS1A-1D, P2-P4 LISS-I-4 Band 1 0.52µm-0.59 µm Band 2 0.62µm-0.68 µm Band 3 0.77 µm -0.86 µm Band 4 1.55 µm-1.70 µm (shortwave infrared) AWiFS Spectral Bands1-4 (same of Multispectral bands, and shortwave infrared bands) IRS P5 & P6 LISS-IV IRS P7 | LISS-I-72.5 m spatial resolution 4 channels (3visible band +1 NIR (near infrared) LISS-II 36.25m spatial resolution 4 Channels (3visible band +1 NIR (near infrared) LISS-III 23.5m spatial resolution 4 Channels(3visible band +1 NIR (near infrared) LISS-III 5.8m spatial resolution PAN 1 Channel (consist of of visible to NIR, black & white) IRS P5 & P6 AWiFS spectral Bands1-4 spatial resolution-56m IRS P7 PAN spatial resolution <1m IRS P7 Swath width 9.6 km | IRIS1A-1D, P2-P4 4 Channels 3 visible and 1 PAN (Panchromatic) LISS1-72.5m LISS2-36.25m LISS3 23.5 m IRS5 & P6 4 Channels 3 visible and 1 PAN (Panchromatic) LISS4 5.8 meters IRS P5 & P6 Spatial Resolution Multiplespectral bands 5.8 m | 1-2 Days 2330Km | Atmospheric, oceanic, land surface, Land surface temperature/emissivity and cryospheric features (sea ice, lake ice, river ice, snow cover, glaciers, ice caps, ice sheets, and frozen ground) | National Urban Information System (NUIS), ISRO Disaster Management Support Programme (ISRO-DMSP) Biodiversity Characterizations at landscape level. Pre-harvest crop area and yield estimation of major crops. Drought monitoring and assessment based on vegetation condition. Mapping flood risk zone, and damage assessment. Hydro-geomorphologic maps for locating underground water resources for drilling well. Irrigation command area status, Mapping urban sprawl and urban developments Urban Environmental Transitions Mapping and monitoring water resource & water pollution Mapping of vector ecology, & breeding habitats environment Epidemic Risk Assessment Spatial prediction of VBD |
| Radar Satellite-1 RISAT1 (Radar Imaging Satellite) | RISAT1 (Radar Imaging Satellite) | Multi-polarization SAR system in C-band active radar sensor system | Spatial resolutions 1-50 m | Swath widths 10-225 km. Repeat cycle 25 days | Day-night imaging capability and cloud penetration high resolution of SAR images | Mapping of vector ecology, & breeding habitats environment |
| Name of the Satellite, & Name of the Country | Camera/ Sensors | Band width & Efficiency of the Satellite | Spatial Resolutions | Repetition & Swath width | Utility of the Remote Sensing data/ Earth Resource Satellite Data Applications | Potential use of satellite data application to VBD Ecology & Control |
|---|---|---|---|---|---|---|
| RISAT2, RISAT-2B RISAT-2BR1 | 6 channel multi-spectral Imager 19 channel sounder Data Relay Transponder (DRT) Satellite Aided Search and Rescue (SAS&R) Bands: C, S, Extended C and Ku bands Charge Coupled Device (CCD) Mid-wave Infrared (MWIR) Long wave Infrared Hyper spectral Imaging (LWIR) A Satellite Aided Search and Rescue (SAS&R) SAR payload with global receive coverage, 406 MHz uplink and 4500 MHz downlink with India coverage | C-band (5.35 GHz) | Very High Resolution Radiometer (VHRR) visible band (0.55–0.75 µm), thermal infrared (10.5–12.5 µm) and water vapour (5.7–7.1 µm) CCD camera in the Visible (0.63–0.69 µm) Near Infrared (0.77–0.86 µm) and Shortwave Infrared (1.55–1.70 µm) MWIR Filters 5 Channels 6.5 - 11.3 µm LWIR Filters 7 channels 12.0 - 14.7 µm INSAT3 series Visible 0.55 - 0.75 µm, SWIR (Short Wave Infrared) 1.55 - 1.70 µm, MWIR (Mid Wave Infrared) 3.80 - 4.00 µm, Water Vapor 6.50 - 7.10 µm, (Thermal Infrared)1 10.3 - 11.3 µm, (Thermal Infrared)2 11.5 - 12.5 µm, TIR- | Ground Resolutions INSAT1 VIS 2.75 km IR channels11 km Visible band ground resolutions 2X2Km Thermal IR and water vapour ground resolutions 8X8Km CCD camera ground resolution 1x1 km INSAT3 series ground resolution 8x8Km INSAT1 series Geostationary coverage total area 145 km2 INSAT3 series 6000 x6000km Coverage with 160 minutes | SAR enable applications in agriculture, monitoring crops, and natural disasters like flood and cyclone, and monitoring environmental changes | Epidemic Risk Assessment Spatial prediction of VBD |
| The Indian National Satellite System (INSAT series), and GSAT Series INSAT-3D, Kalpana, INSAT- 3A, INSAT -3BR SARAL Megha- Tropiques | Operated by ISRO (Indian Space Research Organisation), Department of Space, India | | | | | |
| Oceansat1,2 SCATSAT-1 | Ku-band Scatterometer | | | | Earth observation, weather forecasting, cyclone detection and tracking services Disaster management support Communication , and Navigation | Atmospheric, oceanic, and land surface, temperature/precipitations, emissivity, and atmospheric pressure, and weather forecast. Epidemic Risk Assessment Spatial prediction of VBD |
| ERS (European Resource Satellite) | MSS 3 Bands RA (Radar Altimeter) ATSR-1 (Along-Track Scanning Radiometer) SAR (synthetic aperture radar) operating in C band can detect | 3 visible spectrum bands RA (Radar Altimeter) SAR (synthetic aperture radar) MWR is a Microwave Radiometer | Multispectral visible band 35 days SAR, WSM 3 days | Regular monitoring of land-and ocean-surface processes for change detection. 3 visible spectrum bands specialized for Chlorophyll and Vegetation analysis RA (Radar Altimeter) is a single frequency nadir-pointing radar altimeter | Mapping Vector Ecology A comparative study of spatial auto correlation between LST/ SST and Vector Ecology & Epidemic Transmission SAR can image most of the
| Name of the Satellite, & Name of the Country | Camera/ Sensors | Band width & Efficiency of the Satellite | Spatial Resolutions | Repetition & Swath width | Utility of the Remote Sensing data/ Earth Resource Satellite Data Applications | Potential use of satellite data application to VBD Ecology & Control |
|---------------------------------------------|----------------|----------------------------------------|--------------------|-------------------------|--------------------------------------------------------------------------------|------------------------------------------------------------------|
| changes in surface heights with sub-millimeter precision. Wind Scatterometer used to calculate information on wind speed and direction. | Envisat (ESA) Launched by European Space Agency | MWR (Microwave Radiometer) | Repeat cycle 30 days Swath width 1150 km | Atmospheric chemistry, ozone depletion, biological oceanography, ocean temperature and colour, wind waves, hydrology (humidity, floods), agriculture and arboriculture, natural hazards, monitoring of maritime traffic, atmospheric dispersion modelling (pollution), cartography and study of snow and ice layer Mapping Land, water, ice, forest ecology, geology, sea and wind wave phenomena, bathymetry (water depth), atmospheric physics, and meteorology Monitoring urban growth Mapping and monitoring water resource & water pollution Measuring sea surface temperature Assessing and monitoring health of coastal ecosystems, grass and forest fires SAR can image most of the earth's surface under any weather condition and during day or night | Spatial prediction of VBD Mapping of vector ecology, & breeding habitats environment A comparative study of spatial auto correlation between LST/SST and Vector Ecology & Epidemic Transmission Epidemic Risk Assessment |
Japan's Earth observation satellites

Momo-1 (Marine observing satellite, MOS-1/1b): Optical sensor, and passive microwave sensor
MESSR- No longer operational
MSR- No longer operational
VTIR-The Visible and Thermal Infrared Radiometer (VTIR) for MOS-1 is a scanning radiometer that acquires image data in one visible band and three thermal infrared bands (1 VIS, 3 TIR)
Fuyo-1 (Japanese earth resources satellite, JERS-1): Optical sensor, and active microwave wave sensor (No longer operational)
Midori-1 (Advanced earth observing satellite, ADEOS): Optical sensor, Passive micro wave sensor
Midori-2 (Advanced earth observing satellite, ADEOSII): Optical sensor, and passive microwave wave sensor
Daichi (Advanced land observing satellite, ALOS): Optical sensor, and active microwave wave sensor

SPOT (Satellite Pour l'Observation de la Terre) series
Owned by France
SPOT 1-7 series
"Satellite for observation of Earth"
SPOT1-5 launched by European Space Agency
SPOT 6 and 7 were launched by the Indian PSLV

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|--------------------------------------------|----------------|--------------------------------------|---------------------|------------------------|--------------------------------------------------------------------------|------------------------------------------------------------------|
| Optical sensor                            | High-resolution optical imaging Earth observation satellite system SPOT1-3 5 Channels SPOT4-5 Spectral Bands of VEGETATION Instrument 4 Channels Blue-0.43 µm to 0.47 µm Red-0.61 µm to 0.68 µm Near-infrared 0.78 µm to 0.89 µm Short-wave infrared 1.58 µm to 1.75 µm SPOT6-7 HRV (High Resolution Visible) and HRVIR (High Resolution Visible IR) detectors | HRV Spectral Bands Multispectral X11 0.50 µm - 0.59 µm (Green) Multispectral X12 0.61 µm - 0.68 µm (Red) Multispectral X13 0.79 µm - 0.89 µm (Near IR) HRVIR Spectral Bands Multispectral X11 0.50 µm - 0.59 µm (Green) Multispectral X12 0.61 µm - 0.68 µm (Red) Multispectral X13 0.79 µm - 0.89 µm (Near IR) Monospectral (Red) 0.61µm-0.68 µm | Panchromatic: 10 m Mono-spectral 10 m Multi-spectral: 20 m Spatial Resolution 1 kilometer Swath width 2250 km The SPOT-6 & -7 satellites Spatial Resolution 1.5 m, 2.5m, 5m, 10m, and 20 m Swath width 60-km | SPOT1-5 Repetition 26 days Swath width 60Km Spectral Bands of VEGETATION Instrument Repetition 1-3 days Swath width 2250 km | Land use / Land Cover, Agriculture, Forestry, Geology, Cartography, Regional planning, Water resources Urban landscape planning and other GIS applications Spectral Bands of VEGETATION Instrument Observation of long-term environmental changes on a regional and worldwide scale. | Mapping Land use and land cover Changes Urban planning, Forest cover dynamics Environmental impact analysis Monitoring the irrigation command area status Monitoring urban sprawl and urban developments Urban Environmental Transitions Mapping and monitoring water resource & water pollution Mapping of vector ecology and breeding habitats environment Epidemic Risk Assessment Spatial prediction of VBD |
| MOS-1/1b Instruments 3. VTIR - Visible and Thermal Infrared (TIR) Radiometer 0.6 µm-0.5-0.7 µm 6.5 µm-6.0-7.0 µm 11 µm-10.5-11.5 µm 12 µm-11.5-12.5 µm | VTIR-The Visible and Thermal Infrared Radiometer 4 Channel Spatial resolution VIS channel: 0.9 µm , and IR channels: 2.7 km GLI has 5 focal planes, 2 for VNIR, 2 for SWIR, and 1 MWIR/TIR. VNIR -Visible and near infrared SWIR - Short wavelength infrared MWIR, TIR- Middle and thermal IR ADEOSII VBD -25 bands (380 - 830 nm), 18 channels with 10 nm | MOS 1/1b Repetition cycle 17 days Swath width 1500 km JERS-1 Repeat cycle 44 days Spatial Resolution 20m Swath width 75Km GLI (Global Imager) POLDER-2 Spatial Resolution 6Km X7Km Swath width 2400Km SeaWinds Repeat cycle 1 to 2 days Swath width 1800 km ALOS Spatial | Cadastral Map, Urban planning Agriculture crop yield estimation Forest cover dynamics Ocean resource evaluation Ocean oil spills & pollution Weather prediction Disaster management Water resources & management Urban landscape planning | MOS-1 and MOS-1B satellites: measurement of sea surface temperature (SST), soil water content (moisture), sea wind speed, water equivalent of snow cover, precipitation intensity, sea ice, perceptible water, etc. ADEOS-II are to acquire data contributing for international global change research (carbon cycle, water and energy) | Mapping Land use and land cover Changes Urban Cadastral Map & Urban planning Forest cover dynamics Environmental impact analysis Irrigation command area Monitoring urban sprawl and urban development’s, Urban Environmental Transitions Mapping and monitoring water resource & water pollution Mapping of vector ecology, & |
| Name of the Satellite, & Name of the Country | Camera/ Sensors | Band width & Efficiency of the Satellite | Spatial Resolutions | Repetition & Swath width | Utility of the Remote Sensing data/ Earth Resource Satellite Data Applications | Potential use of satellite data application to VBD Ecology & Control |
|---------------------------------------------|----------------|--------------------------------------|---------------------|------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------|
| ALOS-1, ALOS-2 satellites (Optical sensor, and active micro wave sensor) | Radiometer) and GLI Global Imager (Improved Limb Atmospheric Spectrometer-II), ILAS-II (Improved Limb Atmospheric Spectrometer-II) | bandwidth SWIR - 6 bands 1050 nm-2215 nm TIR - 7 bands (3.715 - 11.95 µm) channels 0.33-1.0 µm bandwidth SeaWinds Radar instruments Wind speed 3m to 20m/s with 2m/s accuracy; wind direction with 20º accuracy wind vector resolution 25 km | Resolution 3–100m Scan cover 25–350Km Repeat cycle Few-14 | cycle | ILAS-II (Improved Limb Atmospheric Spectrometer-II) Polar stratospheric ozone, atmospheric trace gases (O3, HNO3, NO2, NO2, CH4, H2O, CFC-11, CFC-12, C1ONO2, etc.), aerosols, temperature and pressure SeaWinds: weather forecasts near coastlines | breeding habitats environment Epidemic Risk Assessment Spatial prediction of VBD Mapping of spatial topology between vectors and climate parameters |
| JERS-1, ALOS-1, ALOS-2 satellites All are operated by the National Space Development Agency of Japan | | | | | | |
| RADARSAT Radarsat-1, Radarsat-2, Radarsat constellation Canadian Space Agency (CSA) | Active micro wave sensor, etc., Synthetic Aperture Radar (SAR) imaging systems | Radarsat-1 Spatial Resolution 10-100m Scan cover 35 × 500Km Radarsat-2 Spatial resolution 1m-15m | SAR can image most of the earth's surface under any weather condition during day and night times Mapping rain forests, coastal regions, marine oil spills and environmental monitoring track sea ice distribution | Mapping of vector ecology, & breeding habitats environment Epidemic Risk Assessment Mapping of spatial topology between vectors and climate parameters, and spatial prediction of VBD |
| IKONOS1,2 | Optical sensors Panchromatic, and multispectral sensors | Multispectral blue, green, red, near IR Panchromatic Pan 450-900 nm Multispectral Blue-445-516 nm Green-506-595 nm Red-632-698 nm Near IR- 757-853nm | Spatial resolution Panchromatic 0.82 meters; Multispectral 3.28 meters | Swath width 11-13 km Repeat cycle 3 days | Mapping of urban and rural natural resources and of natural disasters, mapping land use revenue and tax, agriculture and forestry analysis, mining, engineering, construction, and High resolution data makes an integral contribution to homeland security, coastal monitoring and facilitates for 3D Digital Terrain Models (DTMs) and Digital Elevation Models (DEM)s. | Mapping land use/ land cover changes Mapping of vector ecology, & breeding habitats environment Epidemic Risk Assessment Spatial prediction of VBD |
| Quickbird 1, 2 Ball Aerospace & Technologies Corp. (P.Ltd.), USA | Optical sensors Panchromatic (PAN) Multispectral (MSS) Near infrared (NIR) | Pan: 65 cm - 73 cm MS: 2.62m -2.90 m Bands: PAN1, and MSS4 Pan: 450-900 nm Blue: 450-520 nm Green:520-600 nm Red: 630-690 nm N IR:760-900 nm Multispectral: 2.62 m - 2.90 m NIR (near infra red) 2.62 m Quickbird 2, PAN- ground resolution 60cm | Swath width 18 Km Repeat cycle Revisit < 10 days | Oil and gas exploration Engineering and construction Environmental studies Mapping Land use / Land Cover Changes, urban sprawl, and urban environmental transitions, monitoring water resource & water pollution, mapping of urban heat island | Oil and gas exploration Engineering and construction Environmental studies Mapping of vector ecology, & breeding habitats VBD Epidemic Risk Assessment Spatial prediction of VBD |
| Name of the Satellite, & Name of the Country | Camera/Sensors | Band width & Efficiency of the Satellite | Spatial Resolutions | Repetition & Swath width | Utility of the Remote Sensing data/Earth Resource Satellite Data Applications | Potential use of satellite data application to VBD Ecology & Control |
|---------------------------------------------|----------------|------------------------------------------|-------------------|---------------------|-------------------------------------------------|---------------------------------------------------------------|
| **World View series**<br>(WorldView-1, WorldView-2, and WorldView-3)<br>NASA, USA | Optical sensor<br>Panchromatic Multispectral<br>Short-Wave Infrared (SWIR)- 8 bands, and 12 CAVIS imagery | Panchromatic: 450nm-800 nm<br>8 Multispectral: (red, red edge, coastal, blue, green, yellow, Near-IR1, Near-IR2) 400 nm - 1040 nm<br>8 SWIR: 1195 nm - 2365 nm<br>12 CAVIS Bands: aerosol-1, aerosol-2, aerosol-3, green, water-1, water-2, water-3, NDVI-SWIR, cirrus, snow) 405 nm - 2245 nm | Spatial resolution PAN 31 cm<br>MSS 1.24m<br>SWIR 3.7m<br>CAVIS 30m | Repeat cycle Revisit ~10 days<br>Mono image: 66.5 km x 112 km (5 strips)<br>Stereo image: 26.6 km x 112 km (2 pairs)<br>Swath width 13.1 km | PAN, MSS, and SWIR: Mapping of urban and rural natural resources and of natural disasters, mapping land use revenue and tax, agriculture and forestry analysis, mining, engineering, construction, and mapping land use/land cover and change detection | High resolution data makes an integral contribution to homeland security, coastal monitoring<br>Environmental studies<br>Mapping of vector ecology, & breeding habitats<br>Epidemic Risk Assessment<br>Spatial prediction of VBD epidemics |
| **Tropical Rainfall Measurement Mission, TRMM**<br>NASA, USA and JNSDA-Japan's National Space Development Agency | 5 Instruments<br>Precipitation Radar<br>TRMM Microwave Imager (TMI), Visible Infrared Scanner (VIRS), Clouds & Earths Radiant Energy System (CERES), and Lightning Imaging Sensor (LSI) | Radar and Active Micro Wave sensors<br>Precipitation Radar (PR), 13.8 GHz<br>TRMM Micro wave five separate frequencies: 10.7, 19.4, 21.3, 37, 85.5 GHz<br>Visible Infrared Scanner 0.63-12 nm | Spatial resolution 4.3Km | Swath width 220 km<br>Data for 24 hours cycle | Distribution and variability of precipitation within the tropics as part of the water cycle in the current climate system<br>Global atmospheric circulation water vapor, clouds, and precipitation<br>rainfall distribution over land and ocean surfaces | Tropical and subtropical precipitation and the associated environmental studies<br>Epidemic Risk Assessment<br>Study of spatial topology between vectors and climate parameters, and spatial prediction of VBD risk prone areas |
| **COSMOSkyMed 1-4 series**<br>Italian Space Agency (ASI) | SAR observation<br>Synthetic Aperture Radar (Active Antenna) | 2 X-band<br>S-band<br>X-band of 300 Mbit/s<br>S-band uplink of 4 kbit/s<br>S-band downlink of 32 kbit/s to 1 Mbit/s | Spatial resolution 1m (High Resolution Mode), 3m (Standard Mode), 20m (Wide Swath Mode) | Scanner cover 10Km -200Km<br>Repeat cycle < 1 day | Global atmospheric circulation water vapor, precipitation, clouds, earthquake hazards, ice sheet monitoring, glaciers changes, agriculture monitoring, landslides monitoring, maritime surveillance | Mapping of vector environment & ecology<br>Study of spatial topology between vectors and climate parameters, and spatial prediction of VBD risk prone areas |
| **TerraSAR-X**<br>TerraSAR-X is of SIR-C/X-SAR (1994) and SRTM (2000) | Synthetic Aperture Radar (Active Antenna) X-band, and S-band<br>X-band of 300 Mbit/s<br>S-band uplink 4 kbit/s (2025-2110 MHz), TerraSAR-X M | TerraSAR-X Mapping flood prone areas, earthquake hazards, ice sheet monitoring glaciers changes, agriculture, land use/land cover change, monitoring, landslides, maritime surveillance | Spatial resolution 5m (High Resolution Mode), 3m (Standard Mode), 20m (Wide Swath Mode) | Scanner cover 5 –100Km<br>Repeat cycle 11 days<br>Operation: 90% of the surface cover within 2 days | High-resolution X-band data applications in hydrology, geology, climatology, oceanography, environmental and disaster monitoring, and cartography (DEM generation)<br>Global atmospheric circulation | Mapping flood prone areas, earthquake hazards, ice sheet monitoring, agriculture monitoring, landslides monitoring, maritime surveillance |
**Table 1**

| Name of the Satellite, & Name of the Country | Camera/ Sensors | Band width & Efficiency of the Satellite | Spatial Resolutions | Repetition & Swath width | Utility of the Remote Sensing data/ Earth Resource Satellite Data Applications | Potential use of satellite data application to VBD Ecology & Control |
|---------------------------------------------|-----------------|----------------------------------------|---------------------|--------------------------|--------------------------------------------------------------------------------|------------------------------------------------------------------|
| European Space Agency (ESA)                 | BPSK modulation 1 band downlink of 32 kbit/s to 1 Mbit/s (2200-2400 MHz), BPSK modulation | TanDEM-X elevation models reveal the glacier's dynamics | Spatial resolution | swath width 5 Km, 30 Km, and 100 km Repeat cycle 28 days | High resolution of SAR images- Ocean and Land resource Management Surveillance of large scale disasters and Environmental Monitoring | Mapping of vector ecology, breeding habitats environment Epidemic Risk Assessment |
| KOMPSAT 1-7 / Arirang 1-7 series            | KOMPSAT series mounted with optical, thermal, and X-band SAR ranges Synthetic Aperture Radar (SAR) | Optical, thermal, and X-band SAR images 9.66 GHz (X-band) 3.2 cm wavelength Synthetic Aperture Radar (SAR) images | Spatial resolution 1m (High Resolution Mode), 3m (Standard Mode), 20m (Wide Swath Mode) | To monitor the mitigation of natural disasters and Environmental Monitoring | Mapping of vector ecology, breeding habitats environment Epidemic Risk Assessment Spatial prediction of VBD |
| KARI (Korea Aerospace Research Institute)   | X band2, L-band Synthetic Aperture Radar (SAR) High resolution images | X-band 150 Mbits/s L-band 1.275 GHz | Spatial resolution 7m (High Resolution Mode), 100m (Standard Mode) | swath within 50 Km, and 400 Km Repeat cycle 16 days | Monitoring urban sprawl and urban developments Urban Environmental Transitions Mapping of vector environment & ecology Study of spatial topology between vectors and climate parameters, and spatial prediction of VBD risk prone areas |
| SAOCOM 1A, 1B Argentinean satellites        | X band2, L-band Synthetic Aperture Radar (SAR) High resolution images | PAN1 Channel 0.420 μm -0.720 μm Multispectral (MSS) (MSS-4 Channel) MS1: (blue) 0.420 μm -0.510 μm MS2: (green) 0.510 μm -0.580 μm MS3: (red) 0.600 μm -720 μm MS4: (near infrared) 0.760 μm -0.890 μm HiRAS spatial resolution 1 m (3 ft 3 in) PAN 2.5 m Multispectral (MSS)-5m Swath width 12.2Km | HiRAS spatial resolution in panchromatic (black-and-white) 2.5 m spatial resolution in multispectral (colour) bands | Mapping Land use / Land Cover Changes Monitoring urban sprawl and urban development’s, Urban environmental transitions, monitoring water resource & water pollution, mapping of urban heat islands, and air pollution risk assessment | Mapping Land use / Land Cover Changes Monitoring urban sprawl and urban developments Urban Environmental Transitions Mapping of vector environment & ecology Study of spatial topology between vectors and climate parameters, and spatial prediction of VBD risk prone areas |
| DUBAI (Dubaisat Satellite Owned by UAE (United Arab Emirates) ) | PAN1, and MSS4 Panchromatic: 1 band Multispectral 4 bands | | | | |

Data derived from Landsat TM, IRS, Spot, ERS, Envisat (ESA), Quickbird, IKONOS, World View series, Tropical Rainfall Measurement Mission, TRMM, NOAA, COSMO-Skymed, MODIS / TERRA, RISAT, INSAT, Oceansat, MOS, SCATSAT, satellite data has positively been used to analyse vegetation, water bodies, monitor air temperature and humidity criterion [18]. Use of MSS and SAR data have been used for mapping of vector breeding potential environment, to examine the vector ecology, spatial topology between vectors and climate parameters, tropical and sub-tropical precipitation and the associated environmental studies, spatial prediction of vector borne diseases risk prone areas, and visualize maps to model malaria risk and its spatial-temporal seasonal variation (Table 1). The malaria risk index rule based maps were used in map overlay analysis to predict spatial stretch of malaria epidemic risk, and to generate cartographic visualize weighted final categorized malaria risk map. The available multispectral earth orbiting satellite data could be served the purpose to study environmental variability. These environmental variables could be monitored and changes must be observed regularly using remote sensing satellite data, thus to pool key data in the GIS expert engine to develop a spatial model to predict the malaria epidemics at least 3-4 weeks early in advance.

**2. Land Resource Satellites Imagery for Mapping Land Use / Land Cover Changes**

More than 3,000 sun synchronous orbit earth resource satellites are currently operating for earth observation
operated by 40 countries. Earth resource satellites provide the information on land use/land cover (LULC) changes systematically with specified interval regular basis, linking these changes with malaria mosquito breeding potentials are significant leads to critical approach for both vector control, and disease prevention. Earth Observation satellites and its applications to survey and determine vector breeding potentiality for forecast malaria in association with land use/land cover changes is fundamental. Huge data sources obtained from different electromagnetic spectrum of various satellites are pursuing the new phase for the development of key elements for assessing the vector potential areas associated with land use/land cover changes. LULC changes are caused by many factors including the man-made and natural, these changes are brought huge impact on vector mosquitoes profusion due to the multiplier effects of industrial developmental projects, climate change, rainfall uncertainty, increasing sea level by global warming, urban development and rejuvenation, transport network developments, deforestation, water resource development projects, tourism development, huge population movements from rural to urban for job seeking, etc. At present, 1950 earth resource satellites are operated in sensing the information relevant to surface features of different land use/land cover categories are directly linked with malaria mosquitoic conditions. Deriving the large amount of data in different temporal and spatial resolution from different multispectral electromagnetic spectrum viz., visible, infrared, and microwave, are found highly significance for linking malaria breeding potentiality and relating disease endemics as well as malaria epidemics spreads.

3. Remote Sensing to Malaria Vector Environment

Malaria outbreaks both longitudinal and vertical magnitude trends have been declined for the past decades, however, the epidemics have been increasingly extended in the third world developing and underdeveloped countries, particularly, it has been challenging problem in the sub-Saharan Africa, Middle and South America, South East Asia, and still it is continued in the major part of East, Northeast India for several decades. Malaria epidemics 229 million cases are registered in the world, and it claims 409,000 deaths in 2019 (WHO, 2020). Sub-Saharan Africa nations alone contributed 93% of all deaths, and below 5 years old children group have registered 61% of death caused by malaria (WHO, 2020). Multispectral satellite data has been used for mapping the malaria vector breeding habitats. Spatial distribution and seasonal variation of malaria vector fecundity are completely controlled by the climate determinants. Synthetic Aperture Radar (SAR) imagery has been used to develop a spatial model for prediction of malaria epidemics in a particular region with risk of susceptible community, and forecast malaria outbreaks much early in advance precisely.

High resolution multispectral satellite data are readily available to process the past and present circumstances of the vector breeding ecology, using visible spectral data viz., 0.40-0.52 μm (Blue), 0.52 μm-0.60 μm (Green), 0.63 μm-0.69 μm (Red), and Infrared imagery (NIR-Near Infrared, MIR-Middle Infrared, TIR-Thermal Infrared) obtained from 0.76 μm -0.90 μm (NIR), 0.90 μm -1.5 μm (MIR) 1.55 μm -1.75 μm (Infrared), Thermal Infrared bands 10.41 μm -12.5 μm, and 2.08 μm -2.35 μm. Climate variations in the land surface temperature (LST) and sea surface temperatures (SST) are determinants of malaria vectors and disease transmission. Land surface temperature (LST), and Sea surface temperature (SST) have been analyzed using the synthetic Aperture Radar (SAR), Advanced Very High Resolution Radiometer (AVHRR), and Microwave Radiometer (MWR). Microwave remote sensing data range from 1cm to 1m were analyzed to environmental monitoring through obtain the information on soil moisture, soil types, water holding capacity of vegetation land cover categories, evapotranspiration from soil and plants, hydrological information, and wet land water logged areas. Knowledge and key elements obtained from the satellite data was used to delineate, analyze and built spatial model to appreciate spatial relationship between the profusion of Anopheles vector species and malaria outbreaks (Table 1). There has been many researchers included the bio-geo environmental variables and climate determinants in the spatial models to predict the malaria epidemics much earlier in advance at least a month before. Climate determinant variables have been used to develop a forecasting system that can be assisted to delineate the geographical boundary of malaria epidemics early in advance, particularly in the Africa continent, and other parts of tropical nations including India where the malaria is severe endemic disease. Climate model was developed based on weather parameters for forecasting malaria outbreaks few months early in advance by the British researchers at Botswana (Africa), and another study shows that malaria outbreaks in the farming community where directly linked with mosquitoic condition from hoof prints to large swamps in association with seasonal huge population movement for farming activities, and are reliably determined by recurrent weather determinants at Tanzania (Africa) [4], similarly, malaria endemic problem persist in the tropical regions of South East Asia, South America, East and North East India, due to mainly climate factors, and land use/landcovers, and wet crops irrigation farming activities, was yield good results accurately, and has statistically significance.

4. Meteorological Satellites Data to Analyze Weather Environment

Meteorological satellites are polar orbiting or geostationary. Seven major groups of unions/organization and/or nations are operating polar orbiting or geostationary satellites for meteorological purposes. Both polar orbiting and geosynchronous satellites are having visible and infrared sensors [10,18]. National Oceanic and Atmospheric Administration (NOAA) series of polar orbiting meteorological satellites, and the Geostationary Operational Environmental Satellite (GOES) series geostationary satellites are operated by the United States America (USA), Metop series satellites operated by the European Union of meteorological satellites (EUMETSAT), Meteor, and RESURS series of satellites operated by Russia, FY-3A, 3B and 3C series by China, and INSAT geostationary satellites owned and operated
5. Climate Determinants and Malaria Transmission

In an urban environment, malaria breeding habitats, vector density, and climate were fuelling for malaria outbreaks, the risk prone areas could be delineated precisely using the multispectral electromagnetic spectrum visible and infrared satellite data. Land use/land cover categories are directly connected with malaria epidemic cases in both rural wet irrigation agriculture farming land, and urban environment [3,6,7]. Among the 400 Anopheles mosquito species, 30 Anopheles vector mosquito species are playing important role as vector in diffusion of malaria. Malaria transmission risk has been shifted from epidemic situation to become endemic and vice versa in Africa continent on the consequences of climate change and its impact on vector fecundity, and climate suitability for parasite development [2]. Most of the malaria epidemic cases were registered in sub-Sahara Africa, including Ethiopia, and the longitudinal trend of malaria cases are irregular pattern of transmission in the pretentious vulnerable community, which is highly determined by the influence of environmental inconsistency, and frequent change of weather determinants [12,14].

As far as the Sub-Sahara Africa concerned, malaria vector Anopheles species including An. gambiae complex (A. arabiensis, A. bwambae, A. melas, A. merus A. gambiae s.s., and A.quadriannulatus) and An.funestusabundance are directly associated with seasonal variations climate factors, viz; temperature, humidity, and amount of rainfall [14]. The information pertain to Land surface temperature (LST), sea surface temperature (SST), normalized differential vegetation indices (NDVI), and evapotranspiration (ET) were derived from the MSS visible, infrared, and SAR microwave remote sensing data. The derived information on LST, SST, NDVI, and ET has been used to analyze the impact of seasonal variation, and environmental variability on spatial and temporal aspects of malaria epidemic pattern in the both endemic and non-endemic regions [10], and the use of remote sensing for time series analyzes for environmental covariant geo-statistical model had best fit and accurate spatial prediction over the temporal pattern of malaria epidemics [12]. Urban growth, deforestation, agriculture land use changes have been bringing regional micro-climatic changes as well as urban heat island, evapotranspiration (i.e. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception), and water bodies, change in atmospheric lower layer troposphere temperature (<15km height from the earth surface) makes important effect on temperature, humidity, and precipitation of weather conditions, effect on human- host-vector-pathogen interaction, and as a result, change in spatial and temporal epidemiology of malaria epidemic transmission, has direct relationship with seasonal variations of the monsoon [2-7,9-16], and statistically significance [6] with p value <0.001.

6. Remote Sensing and GIS in Spatial Model for Forecasting Malaria

The rationale for persistent of malaria endemic situation is not yet revealed, however, the asymmetrical changing ecology of the prime focus of the vector borne disease epidemics have been attracted keen attention including malaria, as it may extent in the newer localities where it was never reported earlier, might have been influenced by the environmental transitions and ecological changes. The conventional manual processes for identification, survey and mapping of Anopheles vector population involves huge money, time consuming, and involves huge intellectual manpower working days, and hence, it is very difficult to conduct a survey to collect vectors in the environmental reservoir. Machine learning algorithms based mathematical models within the Artificial Intelligence (AI) could be used to mapping the probability of areas at risk of malaria transmission, and the risk level leads to manage and control the intricate situation. The occurrence of malaria vectors is determined by the geo-environmental variables and seasonal changes. Artificial Intelligence (AI) is the computer programme based model that serves needs step by step with rapid and accuracy based on the density of vector host population density and the geo-ecological variables leads to spatial prediction of malaria transmission in the human community much earlier in advance. A mobile based healthcare information management system, using the mobile application and cloud computing together for better sharing, storring, updating, and retrieval of electronic healthcare data, so as to be able to forewarn a community early in advance. Based on the map illustrate the areas vulnerable to the high risk of malaria epidemics, could be recommended for full vaccination in the community along with vector strategy in the settlement areas and followed by a systematic surveillance for the control leads to clutch the profusion of Anopheles vector population in and
around the human settlements. Multispectral and Synthetic Aperture Radar microwave remote sensing satellite data have been synchronized in the GIS expert engine to develop a spatial model based on the environmental, climate, and socio-economic risk factors. A big data analysis of malaria epidemic risk factors has been carried out by many researchers, and accomplished that when the value of risk indices exceeds the threshold limit of the determinant variables in a particular place, there could be a chance/highest probability of malaria epidemic outbreaks categorically. Remote Sensing and GIS applications to mapping, monitoring, and spatial modelling for early detection of environmental conditions and change in climate determinant variables have highly been used for prediction of malaria outbreaks [19-25], and has been used to construct a baseline for choosing appropriate measures for malaria mosquito control, prevention and control of malaria diffusion widely [19-25]. An artificial intelligence spatial model has been applied to a routine vector surveillance and control measures could be varied, initiated depends upon the environmental and weather recurrent conditions.

7. Conclusion

Remote sensing of multispectral and SAR microwave satellite data could provide the information on micro level climate changes in the environment, land use/land cover changes, recurrent weather conditions of atmosphere accurately. Gathering the information on climate parameters are reasonably possible at an affordable price, and some extent available in the public domain free of cost, and hence, the expert team of biologists, entomologist, and remote sensing scientist could make use these data for forecast malaria outbreaks for any of the need based regions in the endemic world. Satellite data under the umbrella of GIS could be assisted to assess the risk of malaria outbreaks in various places including inaccessible remote locality. Based on the predicted information, public health officials could make an arrangement for prevention, control measure, and management activities of the outbreak situation successfully.

References

[1] World Malaria Report, World Health Organization (WHO) 2020.
[2] Ryan, S.J., Lippi, C.A. & Zermoglio, F. Shifting transmission risk for malaria in Africa with climate change: a framework for planning and intervention. Malaria Journal, 2020; vol. 19, Article 170.
[3] M.Palaniyandi, T Marriappan, and PK Das. Mapping of land use / land cover and mosquito-genic condition, and linking with malaria epidemic transmission, using remote sensing and GIS, Journal of Entomology and Zoology Studies, 2016; 4(2): 40-47.
[4] Akhtar R. and Mc Michael AJ, 1996. Rainfall and malaria outbreaks in Western Rajasthan. Lancet, 348: 1457-1458.
[5] Thomson, M., Indeje, M., Connor, S., Dilley, M. & Ward, N. Malaria early warning in Kenya and seasonal climate forecasts. Lancet (London, England), 2003; 362, 580.
[6] M.Palaniyandi. Malaria transmission risk in India, Coordinates (GIS e-journal), February, 2013; 9(2): 42-46.
[7] Wood, B.L., Beck, L.R., Washino, R.K., Hibbard, K.A., Salute, J.S. Estimating high mosquito-producing rice fields using spectral and spatial data. Int. Journal of Remote Sensing, 1992; 13(15): 2813-2826.
[8] National Vector Borne Disease Control Programme, Ministry of Health and Family Welfare, Government of India, New Delhi, 2019.
[9] M.Palaniyandi. Red and Infrared remote sensing data for mapping and assessing the malaria and JE vectors’, J of Remote Sensing and GIS, 2014; 3(3): 1-4.
[10] David J. Rogers, Sarah E. Randolph, Robert W. Snow, and Simon I. Hay. Satellite imagery in the study and forecast of malaria, Nature, 2002, February 7; 415(6872): 710-715.
[11] Lisa Sattenspiel. Tropical Environments, Human Activities, and the Transmission of Infectious Diseases, Year Book of Physical Anthropology, 2000; vol. (43): 29 pages, WILEY-LISS, INC.
[12] M.Palaniyandi, PH Anand, and T Pavendar. Environmental risk factors in relation to occurrence of vector borne disease epidemics: Remote sensing and GIS for rapid assessment, picturesque, and monitoring towards sustainable health, Int. J Mos. Res., 2017; 4(3): 09-20.
[13] Midekisa, A., Senay, G., Henebry, G.M. et al. Remote sensing-based time series models for malaria early warning in the highlands of Ethiopia. Malaria Journal; 11, 165 (2012).
[14] Muhammad Haris MAZHER, Javed IQBAL, Muhammad Ahsan MAHBOOB, and Iqra ATIF. Modeling Spatio-temporal Malaria Risk Using Remote Sensing and Environmental Factors, Iran J Public Health, 2018; Sep; 47(9): 1281-1291.
[15] Phillipil Paul, Richard Y M Kangalawe, Leonard E G Mboera. Land-use patterns and their implication on malaria transmission in Kilosa District, Tanzania, Trop Dis Travel Med Vaccines, Jun 20, 2018; 4;6.
[16] Rogers DJ, Randolph SE, Snow RW, Hay SI (2002). Satellite imagery in the study and forecast of malaria. Nature 415:710-715.
[17] Sewe, M.O., Tozan, Y., Ahlm, C. et al. Using remote sensing environmental data to forecast malaria incidence at a rural district hospital in Western Kenya. Sci Rep, 2017; 7, 2589.
[18] Union of Concerned Scientists (UCS) Satellite Database, Published on December 5th, 2005, Updated January 1, 2021. https://www.uccsusa.org/resources/satellite-database.
[19] M.Palaniyandi. The role of Remote Sensing and GIS for Spatial Prediction of Vector Borne Disease Transmission - A systematic review”, Journal of Vector Borne Diseases. 2012; 49 (4): 197-204.
[20] Hassan M. Khormi, and Lalit Kumar. Examples of using spatial information technologies for mapping and modeling mosquito-borne diseases based on environmental, climatic and socio-economic factors and different spatial statistics, temporal risk indices and spatial analysis: A review, Journal of Food, Agriculture & Environment, 2011; Vol:9 (2): 41-49.
[21] M.Palaniyandi. The environmental risk factors significant to Anopheles species vector mosquito profusion, Plasmodium falciparum, Plasmodium vivax parasite development, and malaria transmission, using remote sensing and GIS, Int. J Public Health Research & Development, Oct-Dec., 2021; 12(4): (in press).
[22] Nnadi Nnaemeka Emmanuel, Nniling Zoba, Okolo Mark Ojgba, and Onyudube Kenneth Ikenna. Landscape epidemiology: An emerging perspective in the mapping and modelling of disease and disease risk factors, Asian Pacific Journal of Tropical Disease, 28th September, 2011; 247-250.
[23] Sumana Bhattacharya, C. Sharma, R. C. Dhiman, and A. P. Mitra. Climate change and malaria in India, CURRENT SCIENCE, 2006; 90 (3): 369-375.
[24] M.Palaniyandi, PH Anand, R Maniyosai, T Marriappan, and PK Das. The integrated remote sensing and GIS for mapping of potential vector breeding habitats, and the Internet GIS surveillance for epidemic transmission control, and management, Journal of Entomology and Zoology Studies, 2016; 4(3): 310-318.
[25] Varan Kumar, Abha Mangal, Sanjeet Panesar, Geeta Yadav, Richa Talwar, et al., Forecasting Malaria Cases Using Climatic Factors in Delhi, India: A Time Series Analysis, Malaria Research and Treatment, 2014; Article ID 482851, 6 pages.

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