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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

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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 lager 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 changes3,4, 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 fuelling 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.

Table 1. The use of Earth Observation Satellites data to mapping arthropods vector ecology and forecast epidemics

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 **Landsat TM 4-9** Thematic Mapper (TM) Launched by USA (NASA / USGS)	Optical sensor Landsat1-3 RBV and MSS RBV- Return-Beam Vidicon Return-Beam Vidicon MSS-Multi Spectral Scanner Landsat 4-9 TM, MSS, RCA	**MSS** Band width Green (0.52–0.60 µm) Red(0.63–0.69 µm) Infra Red (0.76–0.90 µm) **Landsat TM 7** TM 7 Bands 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 Band 5, Infra Red	Landsat 1-3 68 X 83 meters Landsat-7 a panchromatic band with 15m spatial resolution a thermal IR channel with 60m spatial resolution TM 4-9 30m, 15m 100m, spatial	Landsat 1-3 18 days 185 Km 30m spatial resolution Landsat 4-9 16 days 185 Km 30m spatial resolution	Mapping Land Use / Land Cover- Level-1,2,3,4 Mapping Land use / Land Cover Changes Monitoring urban growth Mapping and monitoring water resource & water pollution Measuring sea surface temperature	Mapping Land use /Land Cover Changes Monitoring urban sprawl, urban developments Urban Environmental Transitions Mapping and monitoring water resource & water pollution

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	RCA-one broad spectral band (green to near-infrared; 0.505 µm –0.750 µm)	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		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) Launched by USA (NASA / USGS)	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	1-2 Days 2500 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) 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) Launched by India ISRO (Indian Space Research Organisation) Indian Resource Satellite-IRS1A-1D,P2-P4 Mission completed **IRSP5-P7, Cartosat2, Resourcesat1,2, Cartosat1,2,2A-2F Cartosat3 Resourcesat2A** Operated by ISRO, Department of Space, India	**Optical sensor, etc., IRS1A-1D,P2-P4 LISS-1-4** channels 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-72.5m 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)	IRS1A-1D,P2-P4 4 Channels 3 visible and 1 PAN (Panchromatic) LISS1-72.5m LISS2-36.25m LISS3 23.5 m IRSP5&P6 4 Channels 3 visible and 1 PAN (Panchromatic) LISS4 5.8 meters IRS P5 & P6 AWiFS Spectral Bands1-4 spatial resolution-56m IRS P7 PAN spatial resolution <1m IRSP7 Swath width 9.6 km	IRS1C&IRS1D LISS-III Spatial resolution 23.5m Swath width 140 km IRS P6 Spatial Resolution Multispectral bands 5.8 m Swath width 70 km	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 monitoring, Snow-melt run-off estimates for planning water use in downstream projects, mapping land use and land cover, urban sprawl, forest survey, wetland mapping, environmental impact analysis (EIA), Mineral Prospecting, Coastal studies, etc.,	Mapping Land use and land cover Changes Urban planning, Forest survey, Environmental impact analysis Irrigation command area status, Monitoring 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)	**RISAT** (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

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RISAT2, RISAT-2B RISAT-2BR1 Operated by ISRO, Department of Space, India		C-band (5.35 GHz)			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 -3DR SARAL Megha-Tropiques multipurpose geostationary satellite with 4 payloads Operated by ISRO (Indian Space Research Organisation), Department of Space, India	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) SARP payload with global receive coverage, 406 MHz uplink and 4500 MHz downlink with India coverage	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, TIR- (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 VIS 1 km SWIR 4 km MWIR 8 km WV 4 km TIR-1 and TIR-2	**INSAT1 series** Geostationary coverage total area 145 km2 **INSAT3 series** 6000 x6000km Coverage with 160 minutes	**INSAT series** used for television and communications needs of India, broadcasting, meteorology, and search and rescue operations Ocean resource evaluation **GSAT Series** used for digital audio, data and video broadcasting for both military and civilian users	Atmospheric, oceanic, and land surface, temperature/ precipitations, emissivity, and atmospheric pressure, and weather forecast. Epidemic Risk Assessment Spatial prediction of VBD
Oceansat1,2 SCATSAT-1 Operated by ISRO (Indian Space Research Organization)	Ku-band Scatterometer				Earth observation, weather forecasting, cyclone detection and tracking services Disaster management support Communication , and Navigation	
ERS (European Resource Satellite) Launched by European Space Agency	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 3days	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

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	changes in surface heights with sub-millimeter precision. Wind Scatterometer used to calculate information on wind speed and direction.				operating in the Ku-band. SAR (synthetic aperture radar) operating in C band can detect changes in surface heights with sub-millimeter precision. ATSR-1 (Along-Track Scanning Radiometer) is a 4 channel infrared radiometer and microwave sounder for measuring temperatures at the sea-surface and clouds. MWR is a Microwave Radiometer used in measuring atmospheric water	earth's surface under any weather condition and during day and night Mapping Land, water, ice, forest, geology, sea and wind wave phenomena, bathymetry (water depth), atmospheric physics, and meteorology spatial topology between vectors and climate parameters Epidemic Risk Assessment Spatial prediction of VBD
Envisat (ESA) Launched by European Space Agency	Active micro wave sensor 9 Channels MWR, AATSR, MIPAS, MERIS, SCIAMACHY RA-2, ASAR , DORIS, GOMOS	**MWR** (Microwave Radiometer) **AATSR** (Advanced Along Track Scanning Radiometer) **MIPAS** (Michelson Interferometer for Passive Atmospheric Sounding) 0.390 µm -1.040 µm **MERIS** (MEdium Resolution Imaging Spectrometer) **CIAMACHY** (SCanning Imaging Absorption Spectrometer for Atmospheric CHartographY) **RA-2** (Radar Altimeter 2) **ASAR** (Advanced Synthetic Aperture Radar) **DORIS** (Doppler Orbitography and Radiopositioning Integrated) **GOMO** (Global Ozone Monitoring by Occultation of Stars)	Spatial resolution 260m	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	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 Spatial prediction of VBD SAR image provides the earth's surface under any weather condition and during day or night spatial topology between vectors and climate parameters Epidemic Risk Assessment Spatial prediction of VBD

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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	**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 XS1 0.50 µm - 0.59µm (Green) Multispectral XS2 0.61 µm - 0.68 µm (Red) Multispectral XS3 0.79 µm - 0.89 µm (Near IR) Panchromatic P 0.51 µm - 0.73 µm (Visible) **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 Spectral Bands of VEGETATION Instrument 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
Japan's Earth observation satellites Momo-1 (Marine observing satellite: **MOS-1/1b)** : Optical sensor, and passive micro wave 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 micro 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 micro wave sensor **Daichi** (Advanced land observing satellite, **ALOS**) : Optical sensor, and active micro wave sensor		**MOS-1/1b)** Mission 3 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 **JERS-1** Mission Instruments **SAR** (Synthetic Aperture Radar) **OPS** (Optical Sensor) **Midori-1&2** six instruments: AMSR, GLI, ILAS-II, Sea Winds, POLDER-2, Argos **AMSR** (Advanced Microwave Scanning	VTIR-The Visible and Thermal Infrared Radiometer 4 Channel Spatial resolution VIS channel: 0.9 km , 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** VNIR -23 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, &

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ALOS-1, ALOS-2 satellites (Optical sensor, and active micro wave sensor) JERS-1, ALOS-1, ALOS-2 satellites All are operated by the National Space Development Agency of Japan		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 (O_3, HNO_3, NO_2, N_2O, CH_4, H_2O, CFC-11, CFC-12, $ClONO_2$, 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
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	**Radarsat-1** Repeat cycle 24 days **Radarsat-2** Repeat cycle 5-10days	**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 (DEMs).	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	Panchromatic: 65 cm - 73 cm 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 WorldView-1, WorldView-2, and WorldView-3 NASA , USA	Optical sensor Panchromatic Multispectral Short-Wave Infrared (SWIR)- 8 bands, and 12 CAVIS imagery	Panchromatic: 450nm-800 nm 8 Multispectral: (red, red edge, coastal, blue, green, yellow, Near-IR1, Near-IR2) 400 nm - 1040 nm 8 SWIR: 1195 nm - 2365 nm 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 MSS 1.24m SWIR 3.7m CAVIS 30m	Repeat cycle Revisit <10 days Mono image: 66.5 km x 112 km (5 strips) Stereo image: 26.6 km x 112 km (2 pairs) 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 12 CAVIS Bands: aerosols, temperature and pressure, desert clouds, aerosol-1, aerosol-2, aerosol-3, green, water-1, water- 2, water-3 NDVI-SWIR, cirrus, snow	mapping land use/ land cover changes Monitoring aerosols, temperature and pressure, desert clouds, High resolution data makes an integral contribution to homeland security, coastal monitoring Environmental studies Mapping of vector ecology, & breeding habitats Epidemic Risk Assessment Spatial prediction of VBD epidemics
Tropical Rainfall Measurement Mission, TRMM) NASA, USA and JNSDA-Japan's National Space Development Agency	5 Instruments Precipitation Radar 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 Precipitation Radar (PR), 13.8 GHz TRMM) Micro wave five separate frequencies: 10.7, 19.4, 21.3, 37, 85.5 GHz Visible Infrared Scanner 0.63-12 nm	Spatial resolution 4.3Km	Swath width 220 km Data for 24 hours cycle	Distribution and variability of precipitation within the tropics as part of the water cycle in the current climate system Global atmospheric circulation water vapor, clouds, and precipitation rainfall distribution over land and ocean surfaces	Tropical and subtropical precipitation and the associated environmental studies Epidemic Risk Assessment Study of spatial topology between vectors and climate parameters, and spatial prediction of VBD risk prone areas
COSMO-Skymed 1-4 series Italian Space Agency (ASI)	SAR observation Synthetic Aperture Radar (Active Antenna)	2 X-band S-band X-band of 300 Mbit/s S-band uplink of 4 kbit/s 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 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 Study of spatial topology between vectors and climate parameters, and spatial prediction of VBD risk prone areas
TerraSAR-X TerraSAR-X is of SIR-C/X-SAR (1994) and SRTM (2000) **TanDEM-X.** (A German SAR satellite mission, German Ministry of Education and Science)	Synthetic Aperture Radar (Active Antenna) X-band, and S-band X-band of 300 Mbit/s S-band uplink 4 kbit/s (2025-2110 MHz),	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 1m (High Resolution Mode), 3m (Standard Mode), 20m (Wide Swath Mode)	Scanner cover 5–100Km Repeat cycle 11 days 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) Global atmospheric circulation	Mapping flood prone areas, earthquake hazards, ice sheet monitoring, agriculture monitoring, landslides monitoring, maritime surveillance

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 S-band downlink of 32 kbit/s to 1 Mbit/s (2200-2400 MHz), BPSK modulation	TanDEM-X elevation models reveal the glacier's dynamics			water vapor, clouds, glacier, ice cover changes, and precipitation mapping flood prone areas, earthquake hazards, ice sheet monitoring, glaciers changes, agriculture, and landslides, maritime surveillance	Epidemic Risk Assessment Study of spatial topology between vectors and climate parameters, and spatial prediction of VBD risk prone areas
KOMPSAT 1-7 / Arirang 1-7 series Korea Aerospace Research Institute (KARI)	KOMPSAT series mounted with optical, thermal, and X- band SAR ranges Synthetic Aperture Radar (SAR)	Optical, thermal, and X- band SAR ranges 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)	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 Spatial prediction of VBD
SAOCOM 1A, 1B Argentinean satellites	X band2, L-band 1 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	To monitor the mitigation of natural disasters and Environmental Monitoring Mapping flood prone areas	Mapping of vector ecology, & breeding habitats environment, epidemic risk assessment, spatial prediction of VBD
Dubaisat Satellite Owned by UAE (United Arab Emirates) EIAST (Emirates Institution for Advanced Science and Technology)	PAN1, and MSS4 Panchromatic: 1 band Multispectral 4 bands	PAN1 Chanel 0.420 µm -0.720 µm Multispectral (MSS) (MSS-4 Chanel) 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	HiRAIS spatial resolution 1 m (3 ft 3 in) PAN 2.5 m Multispectral (MSS)-5m Swath width 12.2Km	2.5 m spatial resolution in panchromatic (black-and-white) 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

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 subtropical 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 mosquitogenic 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-Sahara 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., 0.0.45 µm-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 mosquitogenic 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/land covers, 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 by India for meteorological purposes (Table 1) [18]. Japan Meteorological Agency (JMA) has the Himawari geostationary satellites, operated for the purpose of weather forecasting, tropical cyclone tracking, and meteorology research [18]. Meteorological agencies of several nations in the East Asia, Southeast Asia, Australia, and New Zealand are using the satellite data for their weather monitoring and forecasting operations (Table 1) [18]. Both polar orbiting satellites and geostationary satellites are operated for monitoring recurrent weather conditions (Table 1). The defence meteorological satellites operated by the United Sates are giving the best results of weather prediction for the North America, South America, and Africa (Atlantic Ocean and Pacific Ocean). Canada uses the GOES system for their meteorological services for weather monitoring, forecasting, tracking storms, and to environmental monitoring of land surface, atmospheric conditions, ocean resource evaluation, cyclone, weather prediction, and climate dynamics. Geostationary satellites are typically used to estimate weather conditions daily; using cloud cover density, cloud height, and aerosol calculations, are obtained and calculated every half hour during the day (Table 1) [18]. Meteorological satellite data are used to appraise even minor variation in the daily weather dynamics, climate pattern, maximum likelihood of seasonal changes, and amount of rainfall, intensity, duration, and thus, malaria mosquito breeding potentiality could be intended [10].

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[1]. 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 *A. 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, storing, 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.

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