Remote Sensing
Concepts and Applications

Rajesh Bahadur Thapa, PhD
Remote Sensing & Geoinformation Specialist
Rajesh.Thapa@icimod.org
https://www.icimod.org/team/rajesh-bahadur-thapa/
Dr. Thapa works at ICIMOD and leads the Group on Land Use Land Cover Change and Ecosystem Services, Geospatial Solutions and the Capacity Development Programme of SERVIR-HKH (NASA-USAID) Initiative, MENRIS Regional Programme. His researches focus on monitoring and assessment of terrestrial environments including forest, agriculture, urban, and disaster thematic areas. He empowers people to use emerging Earth observation and geospatial technologies for making evidence-based decisions to protect the pulse of the planet.

He is an active member of Group on Earth Observations (GEO) Capacity Development Working Group and has 25+ years of work experience across various Asian countries including Japan, Thailand, and the HKH region. Prior to joining ICIMOD, he served at the Japan Aerospace Exploration Agency (JAXA). He was also a visiting professor at the University of Tsukuba, Japan. He holds a PhD in Geoenvironmental Science, MSc in Remote Sensing and GIS, and Master Degree in Geography. Recently, SERVIR Global recognized his remarkable contributions and unwavering commitment to capacity development for connecting space to village mission and awarded prestigious SERVIR Award of Excellence 2019.

https://www.icimod.org/team/rajesh-bahadur-thapa/

Dr. Rajesh B. Thapa
ICIMOD
Email: rajesh.thapa@icimod.org
Remote Sensing Concepts

CONNECTING SPACE TO VILLAGE

Data capture
Platform (satellite)

Data transmission
Ground station data receiving & pre-processing

Application

Data processing, algorithm development, GIS modeling & analysis

GIS
Remote sensing is the science for collecting and interpreting information on targets (objects or areas) without being in physical contact with them.

- It employs electromagnetic energy in the form of radio waves, light, and heat as a means of detecting and measuring target characteristics.
- Remote sensing gathers information about the Earth from a distance, usually from aircraft or satellites.
Remote Sensing Platforms

Ground-based

Aerial-based

Satellite-based
Components of Remote Sensing

- **Energy source:** Sun, irradiance from earth’s materials which is used in passive remote sensing; RADAR, irradiance from artificially-generated energy sources, which is used in active remote sensing.

- **Platforms:** The vehicle which carries a sensor, i.e., balloon, aircraft, space shuttle, satellite, international space station, etc.

- **Sensors:** Device that receives electromagnetic radiation and converts it into a signal that can be recorded and displayed as either numerical data or an image (camera, scanner, radar, etc.).

- **Processing:** Handling remotely sensed signal data, i.e., photographic, digital, etc.

- **Institutionalization:** Organization for executing at all stages of remote-sensing technology to connect space to village.
Remote Sensing Work-flow

A. Energy source
B. Radiation and the atmosphere
C. Interaction with the target
D. Recording of energy by the sensor
E. Transmission, reception, and processing
F. Interpretation and analysis
G. Applications
Basics of RS System: PASSIVE/ACTIVE

Passive satellite/sensors (OPTICAL): Sentinel-2, ALOS AVNIR-2, PRISM; Landsat Series; AVHRR, Spot, MODIS, IKONOS, Quickbird, Worldview, etc.

Active satellite/sensors (RADAR): Sentinel-1, ALOS PALSAR, ALOS-2, RADARSAT, TanDEM-X, TerraSAR-X, etc.

There are also some airborne sensor, such as PiSAR, PiSAR-L2, LiDAR, etc. Recently UAVs based small sensors are also getting popular

Satellite: 300~36000 km; Airborne: ~12 km
Optical vs Radar: same satellite, time & location but different sensors

ALOS AVNIR-2: optical, passive

ALOS PALSAR: radar, active

JAXA – Advanced Land Observing Satellite (ALOS)
Optical vs Radar: Optical

Optical remote sensing makes use of visible, near infrared and short-wave infrared sensors to form images of the earth’s surface by detecting the solar radiation reflected from targets on the ground. Different materials reflect and absorb differently at different wavelengths. Thus, the targets can be differentiated by their spectral reflectance signatures in the remotely sensed images. Optical systems are nadir looking!

- **Panchromatic imaging system:** this is a single channel detector sensitive to radiation within a broad wavelength range. If the wavelength range coincide with the visible range, then the resulting image resembles a "black-and-white" photograph taken from space.

- **Multispectral imaging system:** this is a multichannel detector. Each channel is sensitive to radiation within a narrow wavelength band. The resulting image is a multilayer image which contains both the brightness and spectral (colour) information of the targets being observed.

- **Hyperspectral imaging systems:** This acquires images in about a hundred or more contiguous spectral bands. The precise spectral information contained in a hyperspectral image enables better characterisation and identification of targets.
Optical vs Radar: Radar

Radio detection and ranging (radar) refers to a technique as well as an instrument.

The radar instrument emits electromagnetic pulses in the radio and microwave regime and detects the reflections of these pulses from objects in its line of sight.

The radar technique uses the two-way travel time of the pulse to determine the range to the detected object and its backscatter intensity to infer physical quantities such as size or surface roughness.

Unlike optical, radar systems consists of all-weather and all-day capabilities allowing regular mapping of areas affected by heavy cloud cover, persistent rain, or extended darkness.

Radar systems are side looking! The signals interact differently with the surface than most other sensing systems, providing interesting new information about the observed environment.
Energy from any sources comes in the form of electromagnetic radiation

ER consists of Electrical field (E) and Magnetic field (M), travel at the speed of light (C).

Wavelength and Frequency. The wavelength is the length of one wave cycle, which can be measured as the distance (in m, cm, mm, and nm) between successive wave crests.

Frequency refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in hertz (Hz), equivalent to one cycle per second, and various multiples of hertz. These two are inversely related to each other. The shorter the wavelength, the higher the frequency and vice-versa.
**Electromagnetic Spectrum**

From very short Gamma rays to very long radio waves

<table>
<thead>
<tr>
<th>Passive - optical</th>
<th>Active - microwave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td>X-rays</td>
</tr>
<tr>
<td>$10^{-14}$</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>Visible</td>
</tr>
<tr>
<td>$10^{-8}$</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Visible</td>
<td>Infrared</td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>Infrared</td>
<td>Microwave</td>
</tr>
<tr>
<td>$10^{-4}$</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>Microwave</td>
<td>Radio-wave</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>$1$</td>
</tr>
</tbody>
</table>

Length in meter

<table>
<thead>
<tr>
<th>Active - microwave</th>
<th>Passive - optical</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1$</td>
<td>$10^{-14}$</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>Radio-wave</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>$1$</td>
<td>$10^{-8}$</td>
</tr>
<tr>
<td>Microwave</td>
<td>Visible</td>
</tr>
<tr>
<td>$1$</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Infrared</td>
<td>Infrared</td>
</tr>
<tr>
<td>$1$</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>Microwave</td>
<td>Visible</td>
</tr>
<tr>
<td>$1$</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>X-rays</td>
</tr>
<tr>
<td>$1$</td>
<td>$10^{-12}$</td>
</tr>
</tbody>
</table>

Length in nanometer

Blue (400 – 500), Green (500 – 600) and Red (600 – 700) bands

©2017 Gauri
Spectral Properties of Objects

<table>
<thead>
<tr>
<th>Surface category</th>
<th>Low reflectance</th>
<th>High reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>N-IR (Near-Infrared)</td>
<td>Blue (Visible)</td>
</tr>
<tr>
<td>Vegetation</td>
<td>M-IR (Mid-Infrared)</td>
<td>N-IR (Near-Infrared)</td>
</tr>
<tr>
<td>Soil</td>
<td>Blue (Visible)</td>
<td>M-IR (Mid-Infrared)</td>
</tr>
</tbody>
</table>

- TM B1: High reflectance in water
- TM B4: High reflectance in vegetation
- TM B7: High reflectance in bare soil

©2008 Ko Ko Lwin
Types of Remote Sensing Images

Polar orbit (sun-synchronous), earth resources satellites, Landsat, SPOT, ALOS, IKONOS, QuickBird, etc.

Geostationary orbit, directly over equator at very high altitudes and revolves in the same direction that the earth rotates (west to east), used in metrological, communication and broadcasting applications (e.g., GEOS, Meteosat, EDUSAT, GALAXY-27, KALPANA-1, etc.).
Types of Information from Remote Sensing...

- Field sensor, UAV, Airplane, Satellite...
- Satellite Sensors: Optical, RADAR, MWR, LiDAR etc.
Nadir vs Oblique Viewing

Swath Width or Field of View

Nadir

Low Oblique

High Oblique

Straight Down

Tilted No Horizon Visible

Tilted Horizon Visible
Nadir vs Oblique Viewing

Nadir

Low Oblique

High Oblique
Characteristics of Remotely Sensed Imagery

Remote sensing systems differ in the level of detail or resolution they can capture, and data are available at a variety of resolutions, we will cover four types of satellite resolution:

1) **Spectral Resolution** – refers to the degree to which a satellite sensor can distinguish or resolve features of the electromagnetic spectrum.

2) **Radiometric Resolution** – refers to the number of quantized bits that are used for recording the reflected electromagnetic energy.

3) **Spatial Resolution** – refers to the number of pixels utilized in construction of a digital image. Images having higher spatial resolution are composed of a greater number of pixels than those of lower resolution.

4) **Temporal Resolution** – refers to the frequency of a measurement with respect to time. Often there is a trade-off between temporal and spatial resolution.
The radiometric resolution of image data in remote sensing stands for the ability of the sensor to distinguish different grey-scale values. It is measured in bit. The more bit an image has, the more grey-scale values can be stored, and, thus, more differences in the reflection on the land surfaces can be spotted.

A bit is a binary number that is 0 or 1. For computer processing, the byte unit (1 byte = 8bits; covers integer value between 0-255; or 256 grey levels)
Spatial Resolution

- Landsat 8, 2017
  Kabul Airport
  30m

- World View – 2, 2009
  0.5 m

30 Meters
5 Meters
1 Meter

©2017 Gauri
## Spatial Resolution

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Resolution</th>
<th>Satellite</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeoEye</td>
<td>0.41m</td>
<td>ALOS</td>
<td>2.5m~100m</td>
</tr>
<tr>
<td>Worldview 1, 2</td>
<td>0.46m</td>
<td>ALOS 2</td>
<td>3m~100m</td>
</tr>
<tr>
<td>Pleiades-1A</td>
<td>0.5m</td>
<td>Sentinel 1</td>
<td>5m~100m</td>
</tr>
<tr>
<td>Quickbird</td>
<td>0.61m</td>
<td>Sentinel 2</td>
<td>10m~60m</td>
</tr>
<tr>
<td>Ikonos</td>
<td>0.82m</td>
<td>ASTER</td>
<td>15m</td>
</tr>
<tr>
<td>SPOT 5, 6</td>
<td>1.5 – 5 m</td>
<td>LANDSAT</td>
<td>15m~60m</td>
</tr>
<tr>
<td>Rapid Eye</td>
<td>5m</td>
<td>MODIS</td>
<td>250~1000m</td>
</tr>
</tbody>
</table>

Faisal Masjid, Google Earth Imagery, 18.06.2019
Temporal Resolution

The temporal resolution specifies the revisiting frequency of a satellite sensor for a specific location.

- **High temporal resolution**: < 24 hours – 3 days
- **Medium temporal resolution**: 4-16 days
- **Low temporal resolution**: > 16 days

Settlement bubbles in Manohara (Thapa et al. 2008, City Profile: Kathmandu)
Temporal Resolution - Forest change in Para, Amazon (Radar Data: JERS-1, ALOS/PALSAR)

Forest monitoring! Can any one articulate, what did you see in 2007?
Spectral Bands Commonly Used in Remote Sensing

<table>
<thead>
<tr>
<th>Spectral bands (µm)</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue (0.45 – 0.52)</td>
<td>analysis of water characteristics, water depth, and the detection of subsurface features</td>
</tr>
<tr>
<td>Green (0.52 – 0.60)</td>
<td>water quality studies measuring sediment and chlorophyll concentration</td>
</tr>
<tr>
<td>Red (0.63 – 0.69)</td>
<td>discriminating vegetation types, assessing plant condition, delineating soil and geologic boundaries, and identifying cultural features</td>
</tr>
<tr>
<td>Panchromatic (0.50 – 0.90)</td>
<td>digitally combined with two or three of the multispectral bands to produce color images with spatial detail of the panchromatic image and the spectral detail of the multispectral bands</td>
</tr>
<tr>
<td>Near Infrared (0.7 – 1.0)</td>
<td>useful for vegetation mapping, crop condition monitoring, biomass estimation, and soil moisture assessment</td>
</tr>
<tr>
<td>Shortwave Infrared (1.0 – 3.0)</td>
<td>useful for analyzing moisture levels in soil and for monitoring plant vigor and crop condition, distinguishing clouds from snow and ice</td>
</tr>
<tr>
<td>Medium wave (3.0 - 8) and Long Wave Infrared (8 – 14)</td>
<td>useful to measure the temperature of features such as industrial sites, pipelines carrying heated materials, geothermal sites, and thermal pollution, also useful for the analysis of vegetation stress, soil moisture, and geology</td>
</tr>
<tr>
<td>Microwave region (radar)</td>
<td>useful for mapping of vegetation structure and biomass, flooding, geological sites, etc.</td>
</tr>
</tbody>
</table>
The microwave region of the spectrum is quite large, relative to the visible and infrared, and there are several wavelength ranges from 0.1cm to 100cm (300GHz to 0.3GHz in frequency) with unique code band. Microwaves with longer wavelengths than Ka-band (7.5mm) are generally used as radar. Currently, X-band, C-band, and L-band are in operation in Earth observation satellites, i.e., TerraSAR-X, Sentinel-1, ALOS-2, respectively.
# Spectrum of Microwave Region

<table>
<thead>
<tr>
<th>SAR Band</th>
<th>Frequency</th>
<th>Wavelength</th>
<th>Typical Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ka</td>
<td>27 – 40 GHz</td>
<td>1.1 – 0.8 cm</td>
<td>Rarely used for SAR (airport surveillance)</td>
</tr>
<tr>
<td>K</td>
<td>18 – 27 GHz</td>
<td>1.7 – 1.1 cm</td>
<td>Rarely used (H₂O absorption)</td>
</tr>
<tr>
<td>Ku</td>
<td>12 – 18 GHz</td>
<td>2.4 – 1.7 cm</td>
<td>Rarely used for SAR (satellite altimetry)</td>
</tr>
<tr>
<td>X</td>
<td>8 – 12 GHz</td>
<td>3.8 – 2.4 cm</td>
<td>High resolution SAR (urban monitoring; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)</td>
</tr>
<tr>
<td>C</td>
<td>4 – 8 GHz</td>
<td>7.5 – 3.8 cm</td>
<td>SAR workhorse (global mapping; change detection; monitoring of areas with low to moderate vegetation; improved penetration; higher coherence); Ice, ocean, maritime navigation</td>
</tr>
<tr>
<td>S</td>
<td>2 – 4 GHz</td>
<td>15 – 7.5 cm</td>
<td>Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expands C-band applications to higher vegetation density)</td>
</tr>
<tr>
<td>L</td>
<td>1 – 2 GHz</td>
<td>30 – 15 cm</td>
<td>Medium resolution SAR (Geophysical monitoring; biomass and vegetation mapping; high penetration; InSAR)</td>
</tr>
<tr>
<td>P</td>
<td>0.3 – 1 GHz</td>
<td>100 – 30 Cm</td>
<td>Biomass. First P-band spaceborne SAR will be launched around 2020; vegetation mapping and assessment. Experimental SAR.</td>
</tr>
</tbody>
</table>

Source: *The SAR Handbook* 2019
This figure provides a conceptual overview of the influence of sensor wavelength $\lambda$ on signal penetration into a variety of surface types. The radar signals penetrate deeper as sensor wavelength increases. This is related to the dependence of the dielectric constant $\varepsilon_r$ on the incident wavelength, allowing for higher penetration at L-band than at C- or X-band.
Effects of Different Bands in Surface Penetration

X-band radar image of forested area
Effects of Different Bands in Surface Penetration

P-band radar image of forested area
Side-looking geometry

The figure is a schematic diagram of a radar observation geometry where a platform is moving along a straight path at altitude $H$. Unlike most optical imaging systems, which point their sensors towards nadir, the antenna of imaging radar is pointed away from nadir by a look angle.
A radar antenna (indicated by a gray rectangle) of reasonably short length is moving at a velocity $V$ along its flight path from the right to the left. While moving, it is constantly transmitting short radar pulses and is receiving echoes returned from objects on the ground. Each radar pulse illuminates an instantaneous footprint of size $S$ on the Earth surface.

SAR is an active sensor transmitting a microwave signal towards a target and receive a reflection called backscatter.
How Imaging Radar Works?

Identify the directions for Azimuth and Range

Tips:
Imaging radars are side-looking!
SAR image is constructed from the many pulses reflected by each single target and received by the antenna and registered at all positions along the flight path. Then the image processing algorithm performs range and azimuth compressions to create 2-D SAR image.
Most radars are designed to transmit microwave radiation either horizontally polarized (H) or vertically polarized (V).
Polarizations and Applications

HH is sensitive to flooded forest, logged with trunks remaining, mangrove degradation while HV is sensitive to forest/non-forest contrast, vegetation structure, and biomass.

HH polarization (left) and HV polarization (right). Image source: ALOS PALSAR
### Polarizations and Applications

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Forest</td>
<td>Forest</td>
<td>Deforested</td>
<td>None Forest</td>
</tr>
</tbody>
</table>

- Depending on the transmitting and receiving polarizations, the radiation interacts with object and get backscatters differently. Both wavelength and polarization affect how a radar images the surface.

- Change detection - impact of polarization

- Forest change easily identifiable in HV than in HH polarization!
Scattering Mechanisms

- Three main scattering mechanisms dominate:
  - **Surface scattering**: Water, bare soils, roads – scattering strongly dependent on surface roughness and sensor wavelength
  - **Double-bounce scattering**: Buildings, tree trunks, light poles – little wavelength dependence
  - **Volume Scattering**: Vegetation; dry soils with high penetration – strongly dependent on sensor wavelength and dielectric properties of medium

- At Radar wavelength, scattering is very physical and can be described as a series of bounces on scattering interfaces
Distortions

- Geometric distortion:
  - One side of the mountain seems shorter than the other
- Radiometric distortion:
  - One side of the mountain seems much brighter

Source: The SAR Handbook 2019
Distortions – Geometric

Main geometric distortions on SAR images with their dependence on acquisition geometry.

Source: The SAR Handbook 2019

(Chapter 2. F. Meyer)
Distortions – Geometric

Foreshortening occurs when the radar beam reaches the base of a tall feature tilted away from the radar before it reaches the top. Small incidence angle produces large influence from this distortion. The foreshortened slopes appear as bright features on the image.

Layover occurs when the radar beam reaches the top of a tall feature before it reaches the base. This effect on a radar image looks similar to that due to the foreshortening. Small incidence angle also produces large influence from this distortion.

Shadow occurs when the radar beam is not able to illuminate the ground surface behind tall features or slopes. Large incidence angle produces large shadowed area.
Distortions

Geometrically Terrain Corrected Image

Source: The SAR Handbook 2019

ALOS PALSAR (L-band) data © JAXA (2007)
Distortions

Image after Radiometric Terrain Corrections

Source: The SAR Handbook 2019
Distortions – Radiometric

Original SAR Image
SAR data © AeroSensing GmbH

Speckle Filtered
Bayesian Algorithm

Speckle reduction
Distortions – Radiometric

• Noise caused “Speckle” which is an inherent property of all coherent imaging systems

• Technically, it looks noise but it is not, it is an interference pattern
Remote Sensing Applications
There are so many applications of remote sensing...

- Urban monitoring
- Water resources monitoring
- Weather and climate services
- Agriculture and food security
- Land use land cover, and ecosystem
- Disaster monitoring, emergency response, and management
- Topographic mapping
- Forest monitoring
- Measuring motion of the Earth’s surface to understand earthquakes and volcanoes and support emergency management efforts.
- Studying the movements and changing size of glaciers and icecaps to explain long-term climate variability.
- Assessing geology, geophysical structure, and terrain for the likelihood of finding oil, gas or other natural resources.
- Monitoring of oil spills, etc.
Urban Monitoring (Sector G13, Islamabad)

2007.09.07

2008.05.05

Google Earth Imagery

8 Months
Urban Monitoring (Sector G13, Islamabad)

2014.09.01  6 Years  2020.04.22

Google Earth Imagery
Urban Monitoring (Jamuna Future Park, Dhaka)

2001.03.21
Urban Monitoring (Jamuna Future Park, Dhaka)

2008.06.11

7 Years
Urban Monitoring (Jamuna Future Park, Dhaka)

2017.02.05

9 Years
Urban Monitoring (Kathmandu – Boudha area)

CORONA Satellite Imagery, 05.02.1967
Urban Monitoring (Kathmandu – Boudha area)

SPIN-2 Satellite Imagery, 05.02.1991
Urban Monitoring (Kathmandu – Boudha area)

GeoEye Satellite Imagery, 23.01.2010

19 Years
Kathmandu - Land use/cover mapping, change monitoring, & modeling

Thapa et al. (2009), Remote Sensing; Thapa (2012), SPIE Proceedings; Thapa et al. (2012), Landscape and Urban Planning
There are many applications ...our recent book on applications...

SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation
Editors: África F. Anderson, Kelsey E. Herndon, Rajesh B. Thapa, Emil Cherrington

- Freely-available eBook, interactive pdfs, and training modules; result of a 2-year joint collaboration between NASA SERVIR & SilvaCarbon
- Applied content, hands-on trainings to get started using Synthetic Aperture Radar (SAR) for forest monitoring, biomass estimation, mangrove extent, time-series analysis
- Authored by world-renowned SAR experts from the NISAR Science Team, US Forest Service, academia
- Reviewed and tested by the SERVIR-Global network
- Downloadable open-source scripts and sample datasets for a variety of forestry applications; useful for beginners to experts

For more information, visit the SERVIR website @ SERVIRglobal.net

Selected pages from Chap 6: Radar Remote Sensing of Mangrove Forests (by Dr. Marc Simard, Sr. Scientist & mangrove specialist, NASA Jet Propulsion Laboratory)
Major highlights

- This open access book is a consolidation of lessons learnt and experiences gathered in 19 chapters from its decade long efforts on applications of Earth observation science and geospatial information technologies to address regional and local needs in the Hindu Kush Himalayan region.

- The book highlights SERVIR’s approaches to innovative applications in – agriculture and food security; land cover and land use change, and ecosystems; water resources and hydro-climatic disasters; and weather and climate services.

- It offers a collection of multi-disciplinary topics with practically tested applications in the region.

- The book is a complete package of knowledge and learnings on project cycle including service area planning, stakeholder consultation, user engagement, capacity building, monitoring and evaluation, gender integration, and communications.

DOI: 10.1007/978-3-030-73569-2
Thank you

Let’s protect the pulse.