"Role of Artificial Intelligence in Flood Management & Monitoring : Concept, Scope & Challenges"

"SDMC (IU) Workshop
on
"Integrated Flood Risk Management"."

At

SAARC Disaster Management Centre (IU),
Gandhinagar, Gujarat, India

Prof. Deepak Khare
BIS Chair Professor & Professor (HAG)
Department of Water Resources Development and Management
Indian Institute of Technology Roorkee
deepak.khare@wr.iitr.ac.in   9412990808

Date:09 December 2023

Artificial Intelligence in Flood Management

- Water Resources:
- Flood Management
- Application of AI

Floods in 2023

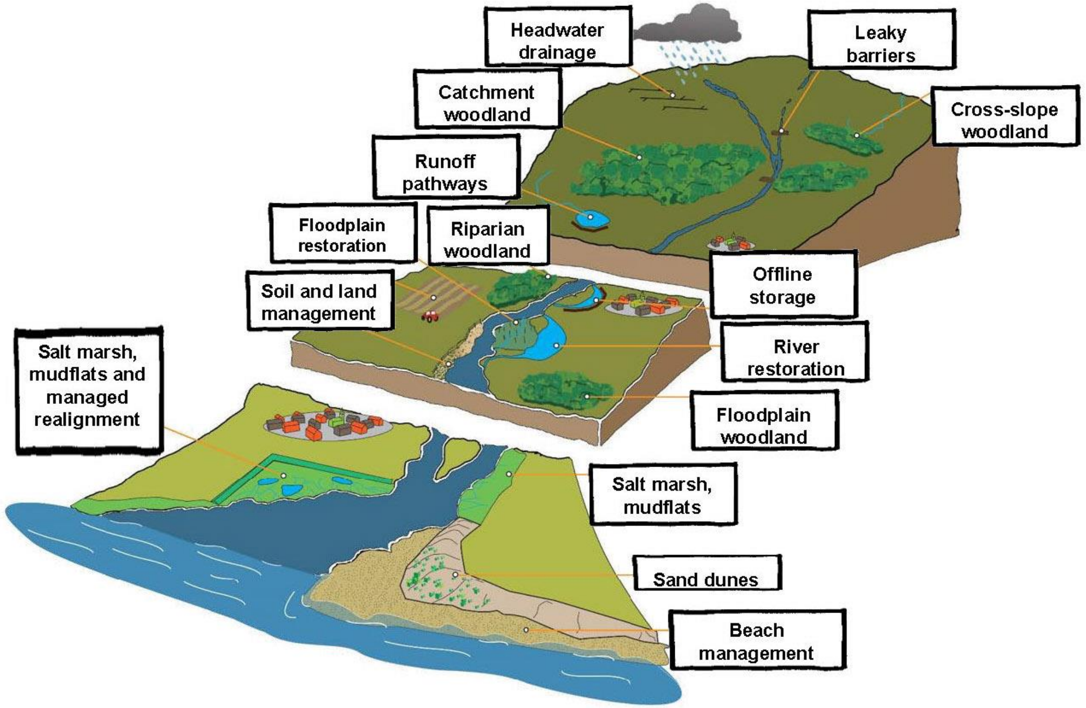
Floods in India 2023

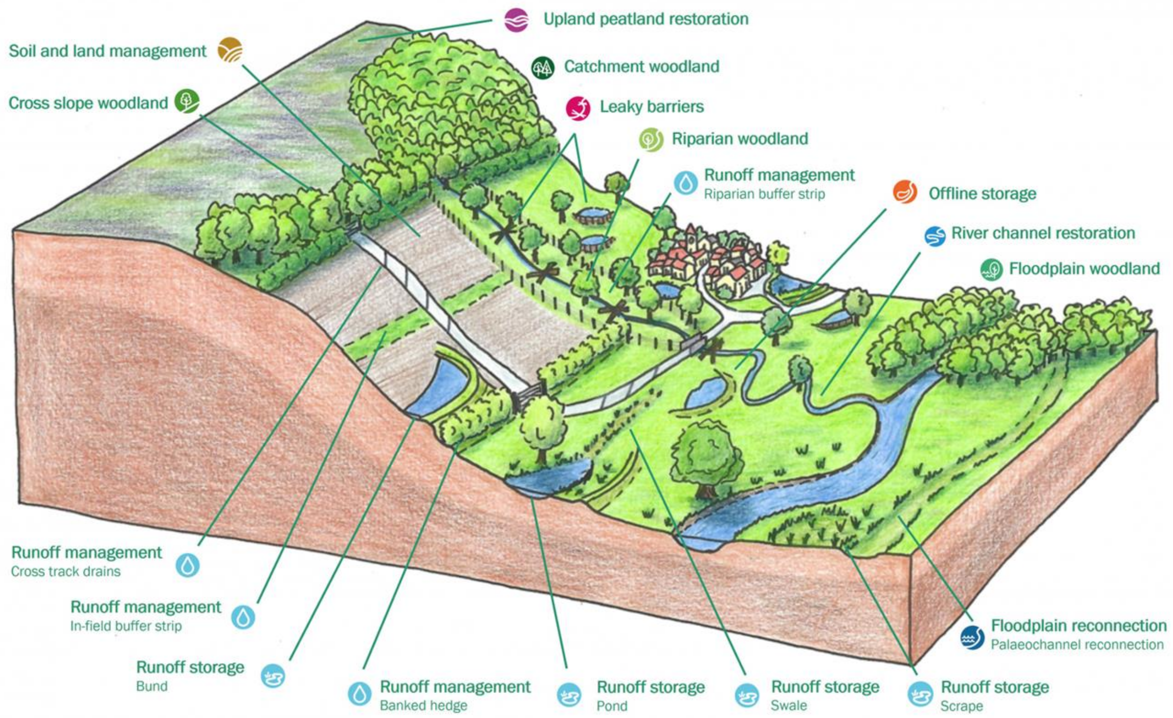
North India

Floods in Dubai Nov- 2023

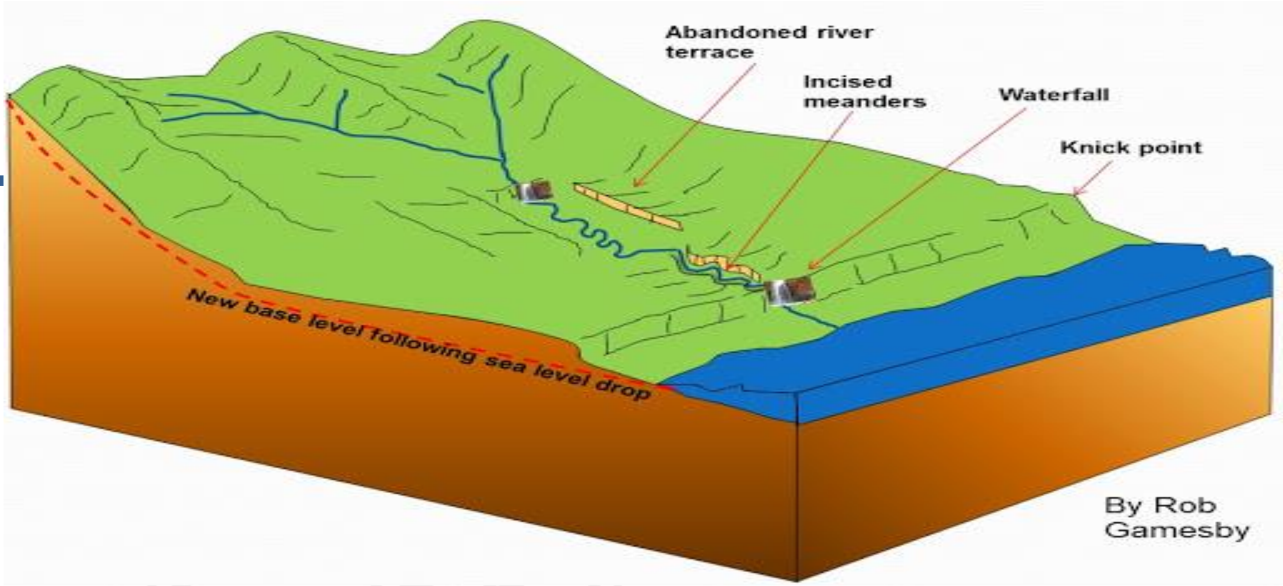
Flooding Hits Spain, Greece, Turkey, Bulgaria

Floods in China 2023



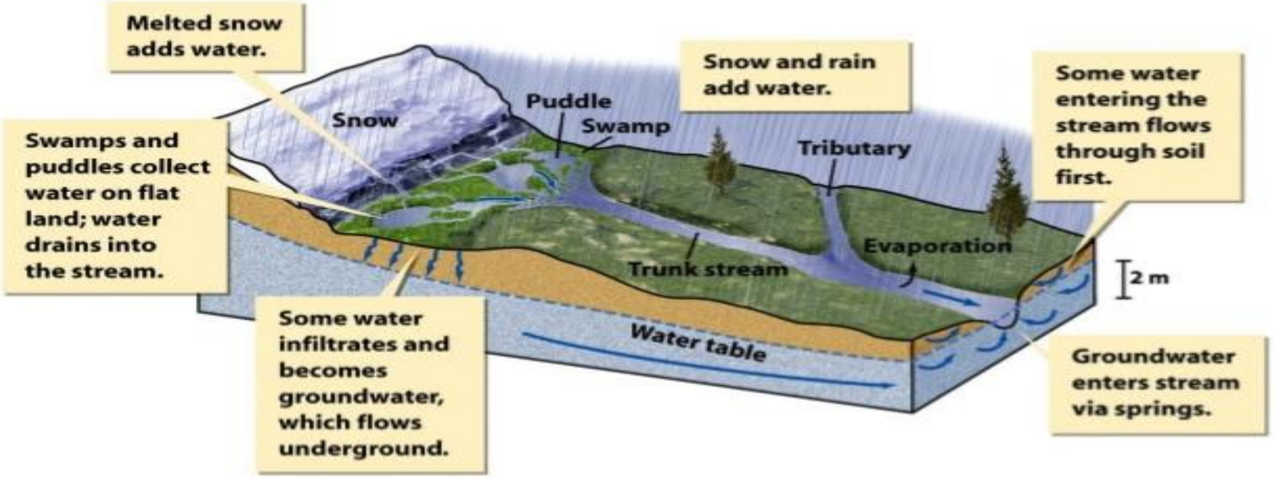


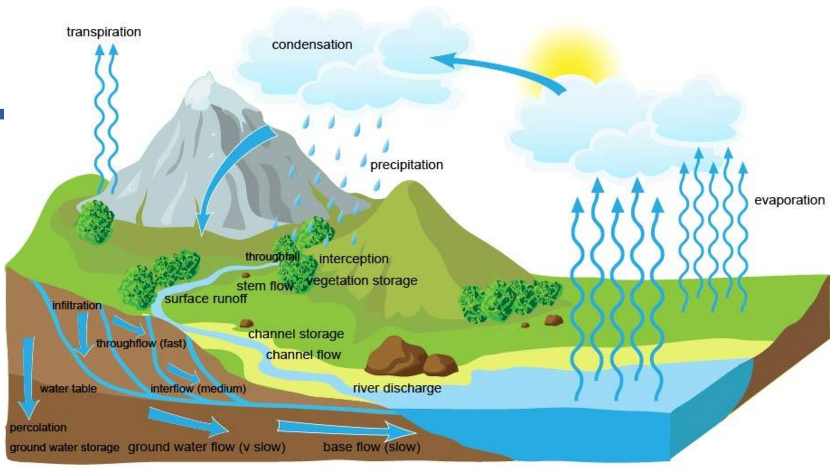
[What is Natural Flood Management?]

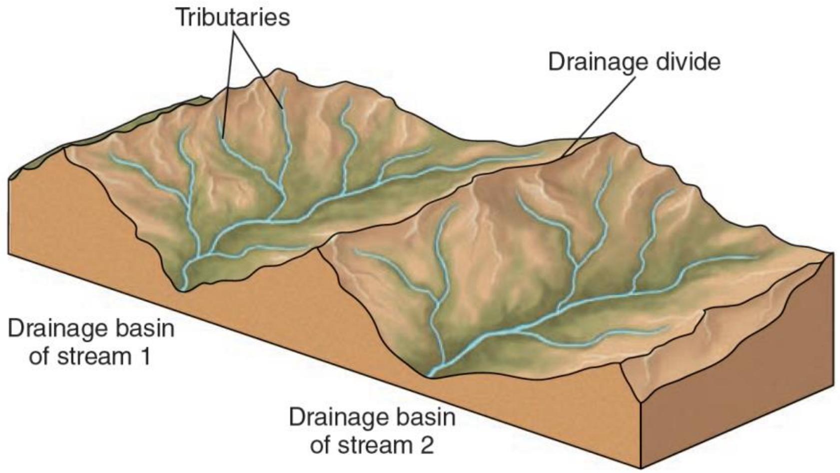


Forming Streams

- Streamflow begins as water is added to the surface





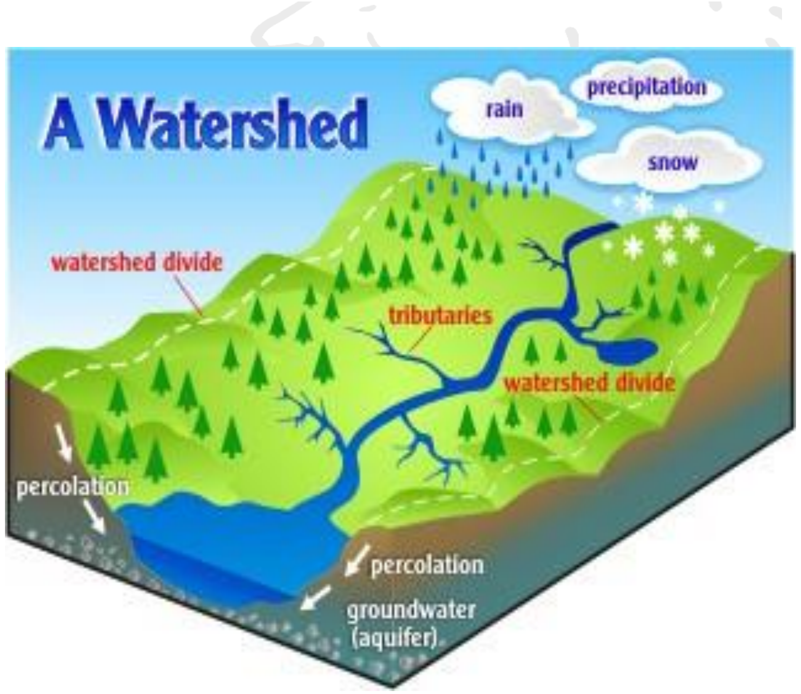


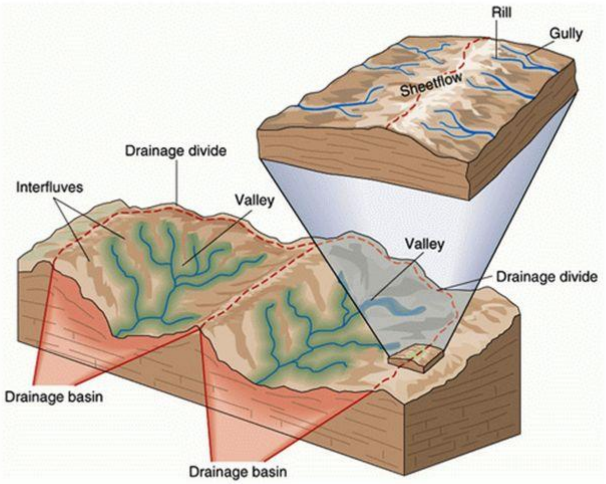
Drainage Basin

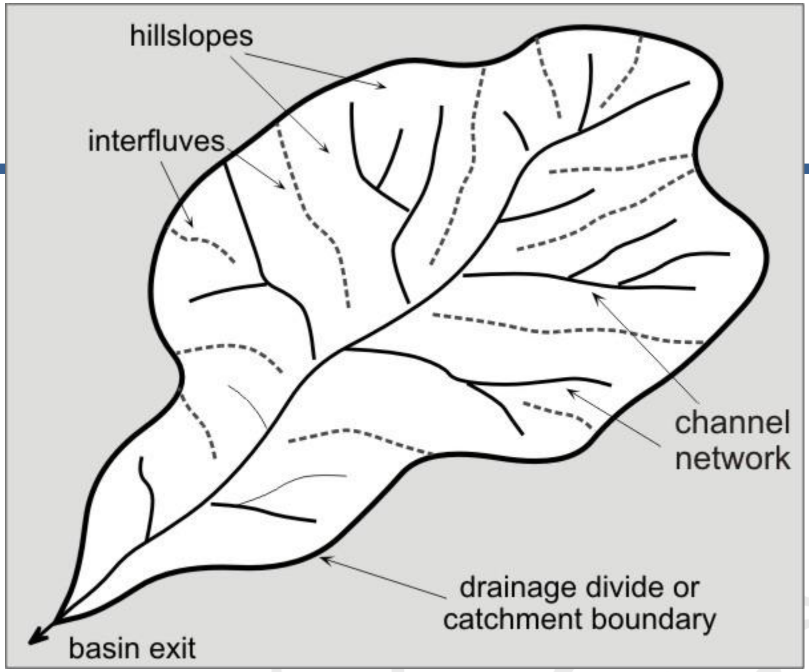
drainage basin - the total land surface drained by a system of streams leading to the same outflow.

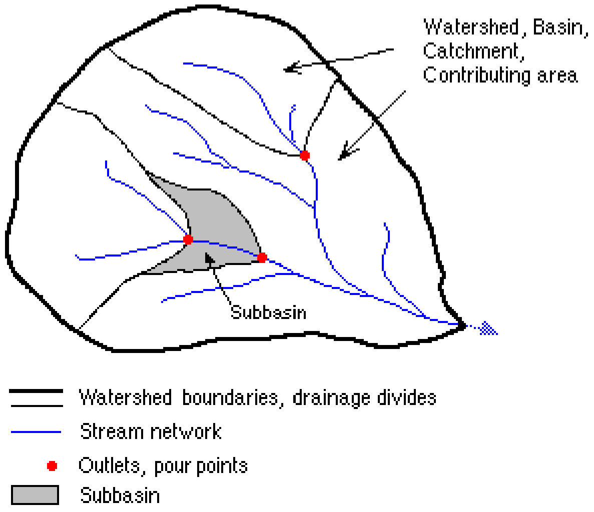
drainage system - the streams, tributaries, and other bodies of water by which a region is drained.

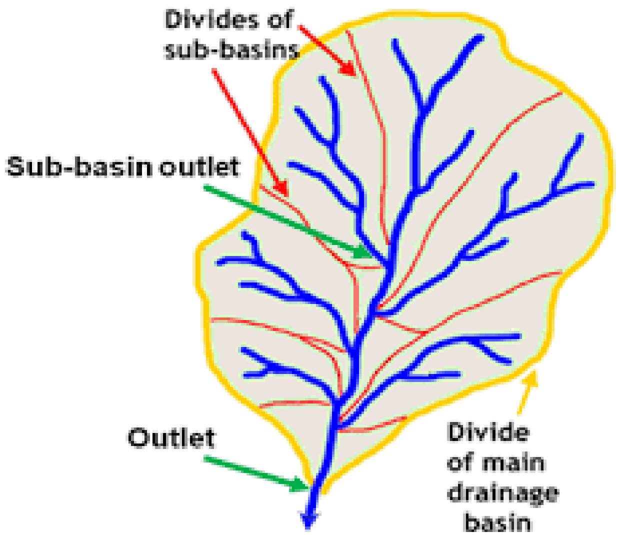
drainage divide - the boundary between adjacent drainage basins.

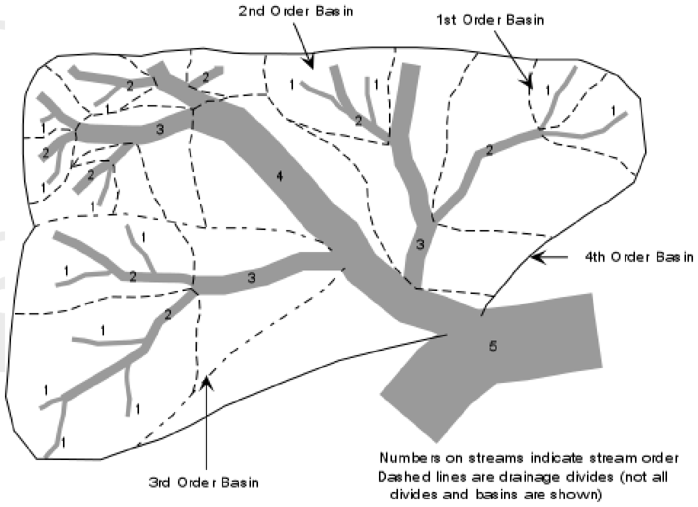





hillslopes
interfluves
channel network
drainage divide or catchment boundary
basin exit


Watershed, Basin, Catchment, Contributing area
Subbasin
Watershed boundaries, drainage divides
Stream network
Outlets, pour points
Subbasin

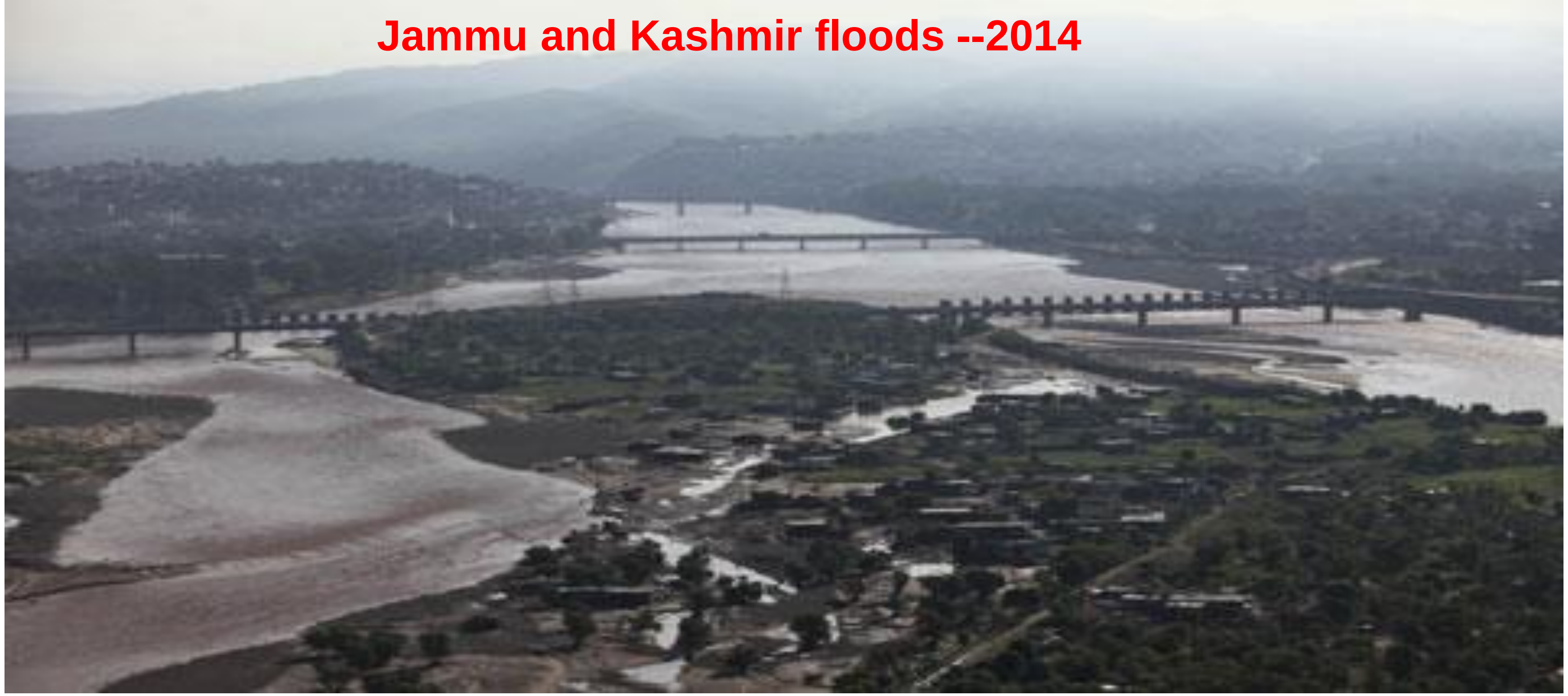

Divides of sub-basins
Sub-basin outlet
Outlet
Divide of main drainage basin


2nd Order Basin
1st Order Basin
4th Order Basin
3rd Order Basin
Numbers on streams indicate stream order
Dashed lines are drainage divides (not all divides and basins are shown)

UTTARAKHAND FLOODS OF 2013


JAMMU AND KASHMIR FLOODS - 2013

Jammu and Kashmir floods --2014



Jammu and Kashmir floods --2014

'Unprecedented Rains, Unplanned Urbanisation Reasons Behind J&K floods'

- It is a combination of an intense and unprecedented rainfall event combined with mismanagement (of drainage) and unplanned urbanisation and lack of preparedness
- In the last 100 years, more than 50 per cent of the lakes, ponds and wetlands of Srinagar have been encroached upon for constructing buildings and roads.
- The banks of the Jhelum river have been taken over in a similar manner, vastly reducing the river's drainage capacity. Naturally, these areas have suffered the most,“
- The Kashmir floods --are a grim reminder that climate change is now hitting India harder. In the last 10 years, several extreme rainfall events have rocked the country and this is the latest calamity in that series," due to such extreme events which includes Mumbai floods of 2005, Leh cloudburst of 2010 and the Uttarakhand floods of 2013.
- In Jammu and Kashmir floods further highlighted that there has been "unseasonal and extreme rainfall" and at many places as it rained more than 200-mm in 24 hours –- 400 per cent more than the monthly average.

Flood Management

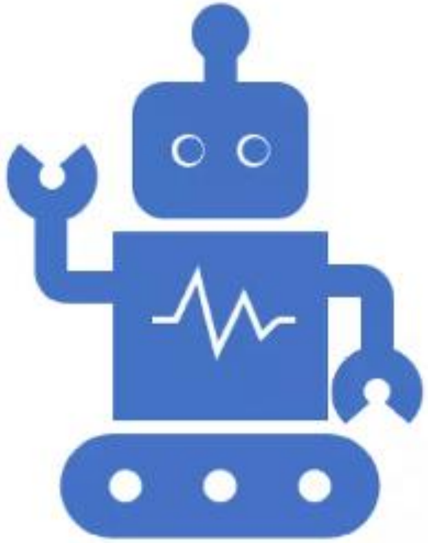
Structural Measures

- Reservoirs
- Embankments, flood walls
- Drainage improvement through Drainage channels
- Diversion of floods

Flood Management

Non-structural Measures

- Early warning systems – flood forecasting
- Disaster Response Team
  - Trained and well equipped
    - Recent J&K flood is a case in point where our preparation is inadequate
    - Army deployed for rescue
- Vigilant administration
- Co-ordination amongst Central/ State agencies



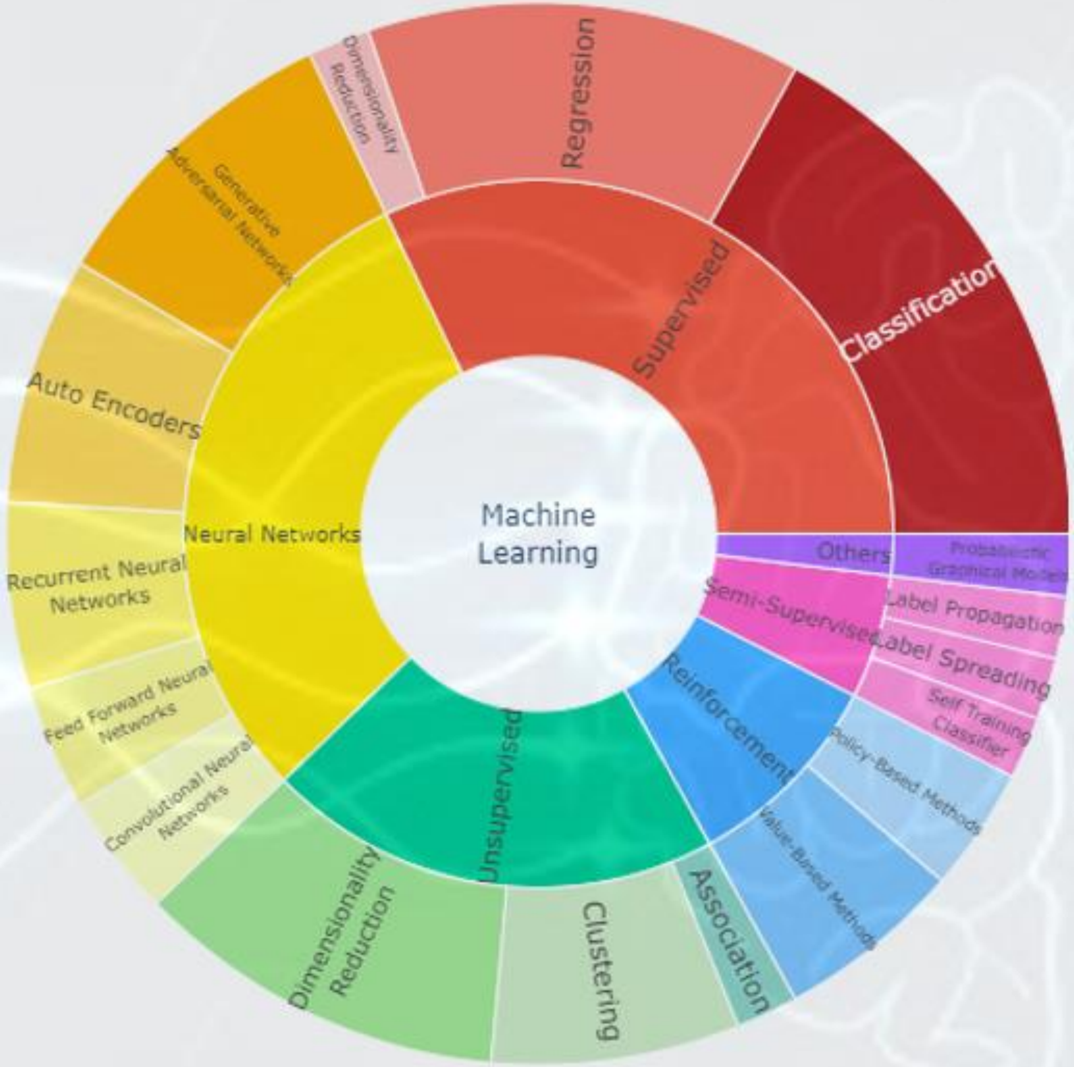
WHAT IS AI ?

- Artificial intelligence (AI) is a wide-ranging branch of computer science concerned with building smart machines capable of performing tasks that typically require human intelligence.
- Artificial intelligence is widely used to provide personalised recommendations to people, based for example on their previous searches and purchases or other online behaviour.
- AI is hugely important in commerce: optimising products, planning inventory, logistics etc.

WHAT IS AI ? CONTD.

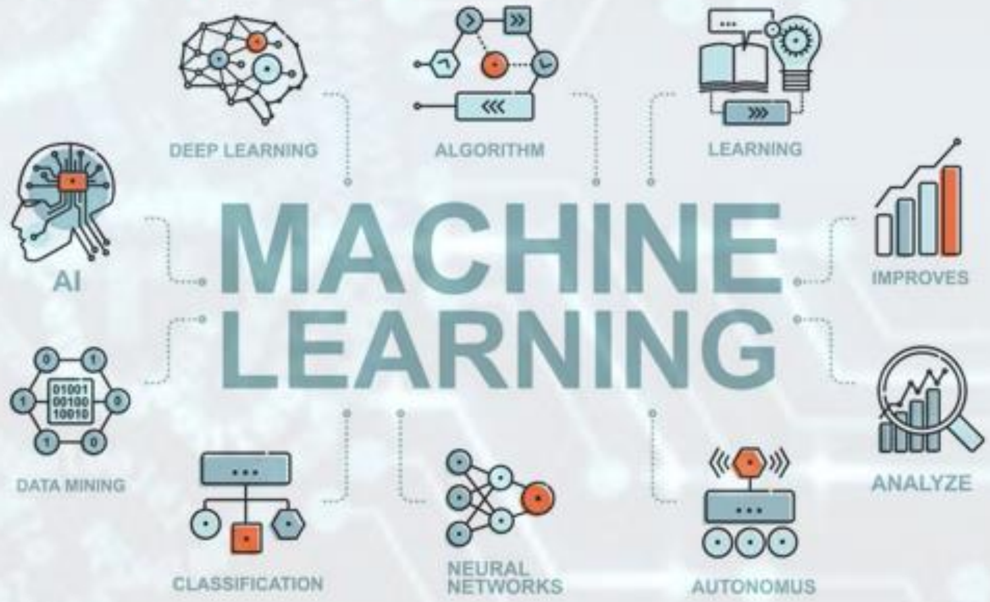
- The term is frequently applied to the project of developing systems endowed with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalize, or learn from past experience.
- Basic logic behind AI is the information processing by a neural network which can adapt itself based on responses, just like human brain.
- AI can also be used for solving water resource related problems as water resource problems are highly adaptive and changes with both time and space.
- Some of the example application of AI is delineated in this presentation

Detailed overview of Machine Learning models



Basic types of Machine Learning

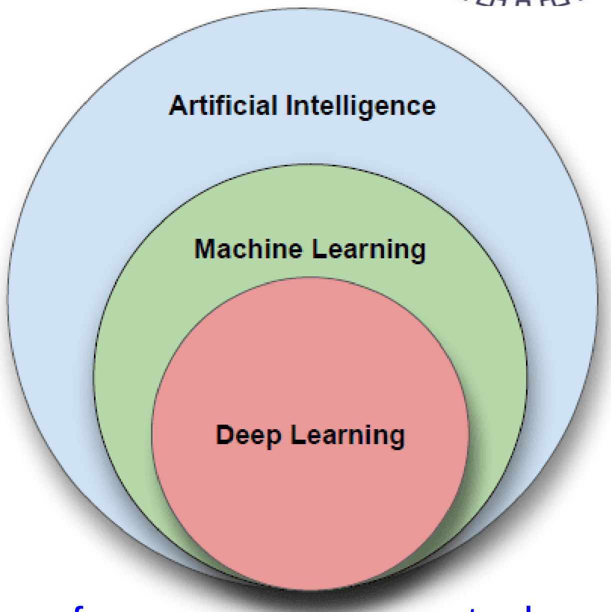
- Supervised learning
- Unsupervised learning
- Reinforcement learning
- Deep learning



Workflow of Machine Learning models

Different fields under AI to clear common misconceptions

Artificial Intelligence is the most trending field of computer science. However, with all the new technology and research, it's growing so fast that it can be confusing to understand what is what. Furthermore, there are many different fields within AI, each one having its specific algorithms. Therefore, it's essential to know that AI is not a single field but a combination of various fields.



Artificial Intelligence (AI) is the general term for being able to make computers do things that require intelligence if done by humans. AI can be broken down into two major fields, Machine Learning (ML) and Neural Networks (NN). Both are subfields under Artificial Intelligence, and each one has its methods and algorithms to help solve problems.

Machine learning

Machine Learning (ML) makes computers learn from data and experience to improve their performance on some tasks or decision-making processes. **ML uses statistics and probability theory for this purpose**. Machine learning uses algorithms to parse data, learn from it, and make determinations without explicit programming. Machine learning algorithms are often categorized as supervised or unsupervised. Supervised algorithms can apply what has been learned in the past to new data sets; unsupervised algorithms can draw inferences from datasets. Machine learning algorithms are designed to strive to establish linear and non-linear relationships in a given set of data. This feat is achieved by statistical methods used to train the algorithm to classify or predict from a dataset.

Deep learning

Deep learning is a subset of machine learning that uses multi-layered artificial neural networks to deliver state-of-the-art accuracy in object detection, speech recognition and language translation. Deep learning is a crucial technology behind driverless cars and enables the machine analysis of large amounts of complex data — for example, recognizing the faces of people who appear in an image or video.

Applications of Machine Learning in Water Resources

Water demand forecasting: Machine learning algorithms can be used to analyse historical water usage patterns and make predictions about future demand, allowing for more efficient water distribution and reducing the likelihood of water shortages.

Drought prediction: Machine learning algorithms can be used to predict droughts by analysing various factors such as precipitation, temperature, and soil moisture levels, and providing early warnings for water management and conservation efforts.

Flood prediction: Machine learning algorithms can be used to predict floods by analysing various factors such as precipitation, runoff, and water level data, and providing early warnings to mitigate the impact of floods.

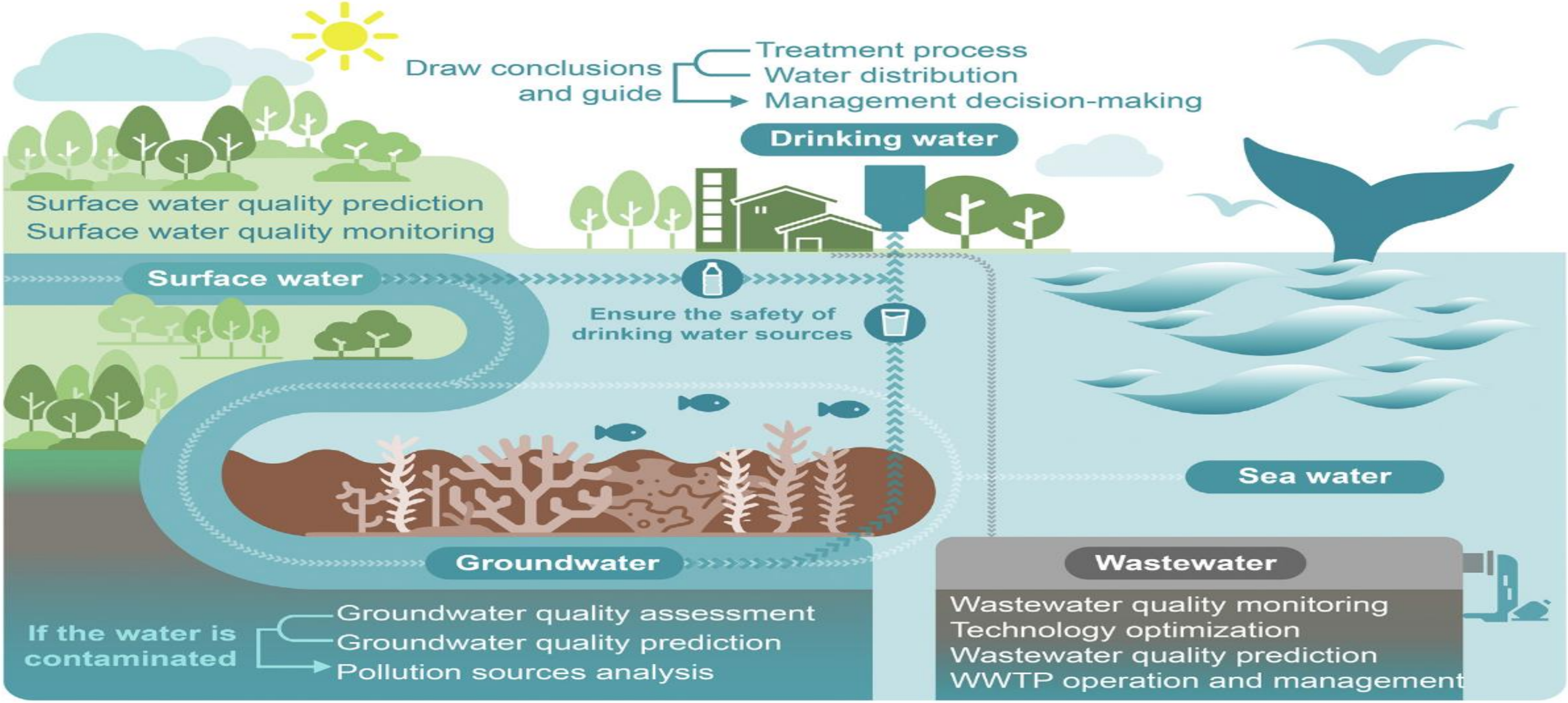
Water quality monitoring: Machine learning algorithms can be used to analyse water quality data, identify patterns and anomalies, and provide early warnings of potential issues, allowing for quick action to be taken to maintain water quality.

Irrigation systems: Machine learning algorithms can be used to optimize irrigation in agriculture, by predicting soil moisture levels, predicting weather patterns, and making decisions about water usage based on real-time data.

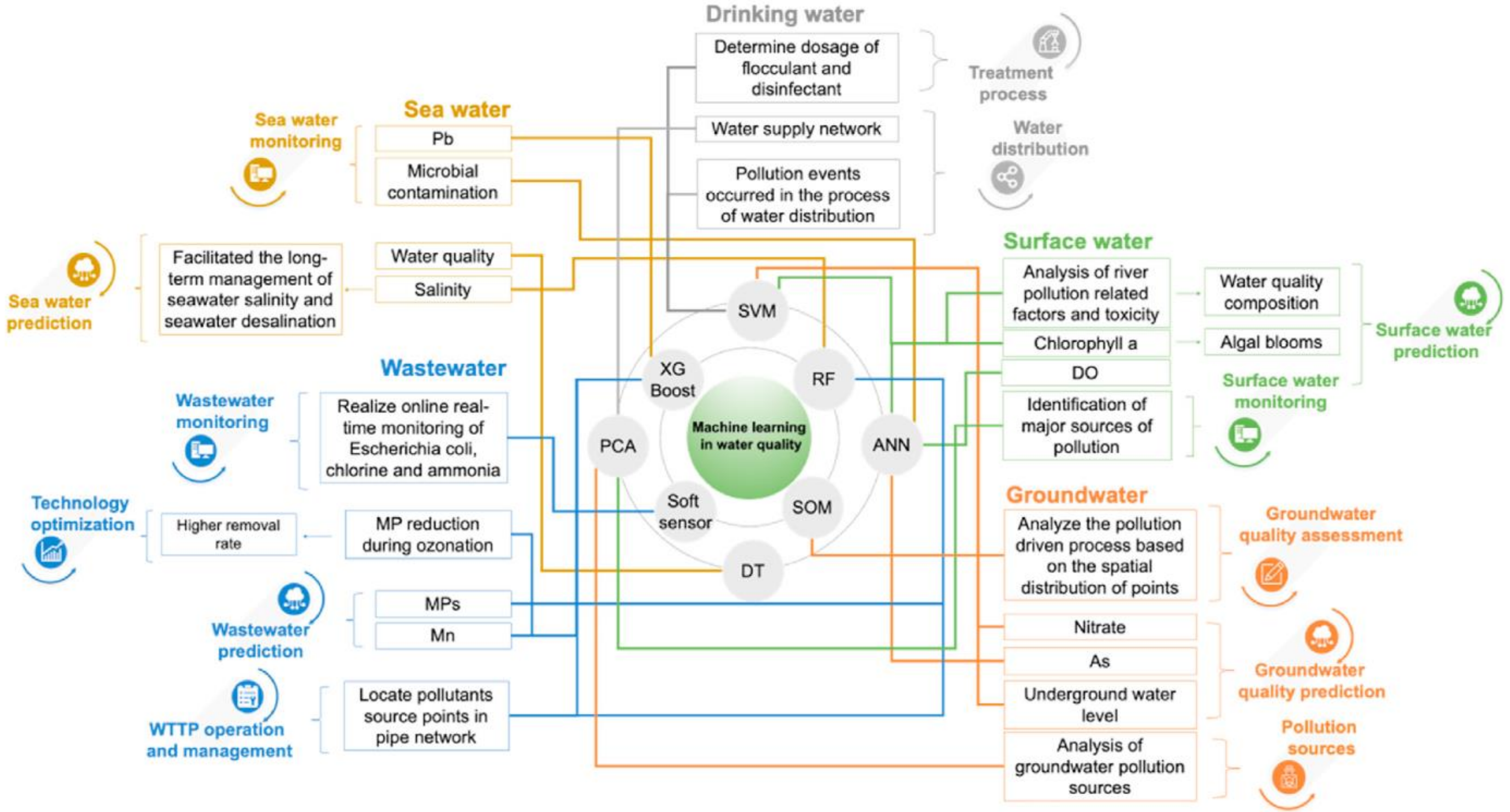
Predictive maintenance: Machine learning algorithms can be used to predict the likelihood of a failure in water infrastructure, allowing for preventative maintenance to be carried out before the failure occurs.

Various sectors of Machine Learning models

- **Surface water resources** **Groundwater resources** **Wastewater resources**
- **Sea water resources estimation and modeling** **Drinking water and sanitization.**



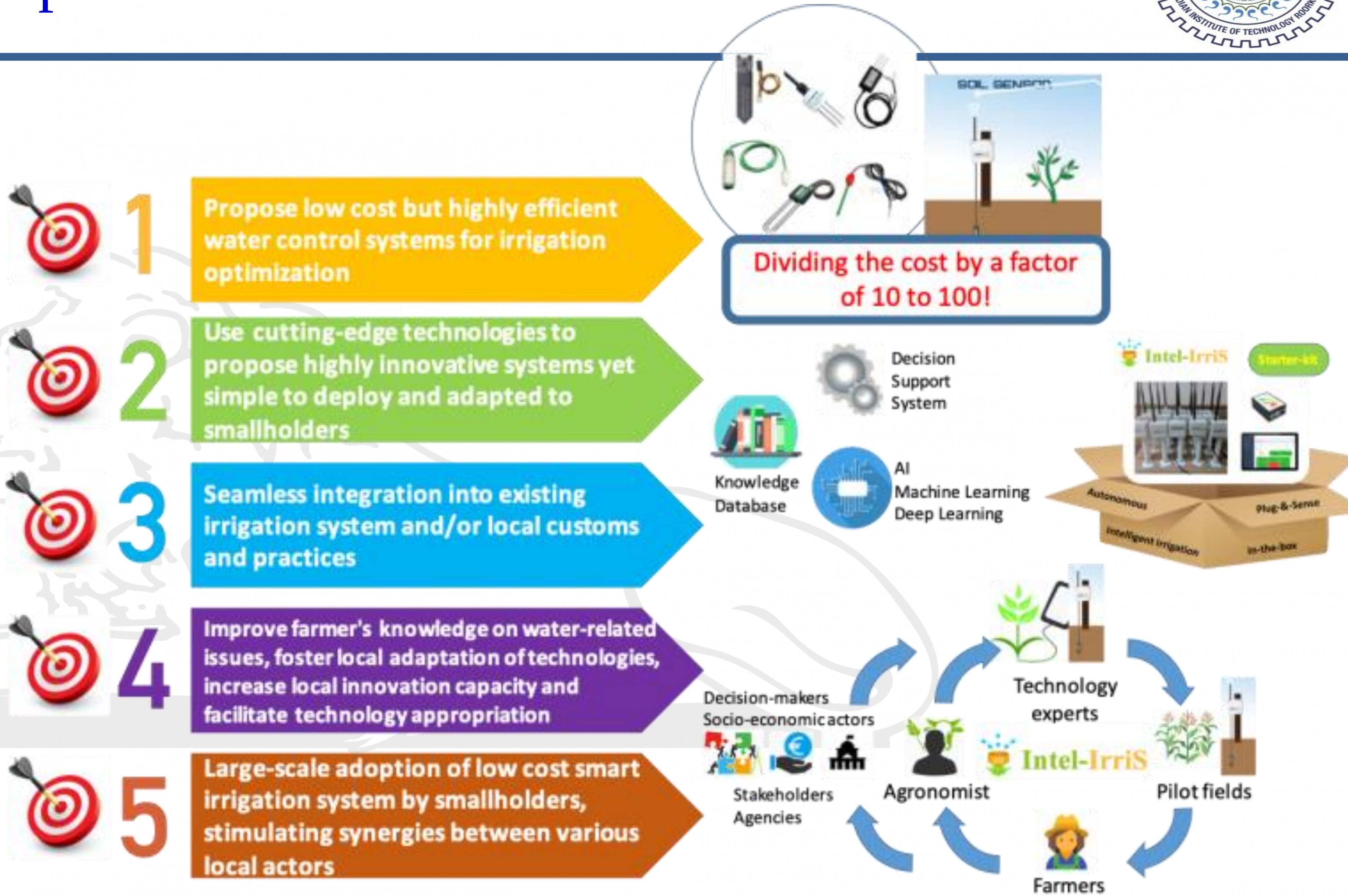
Detailed application of Machine learning in Water resources



Irrigation Systems Optimization

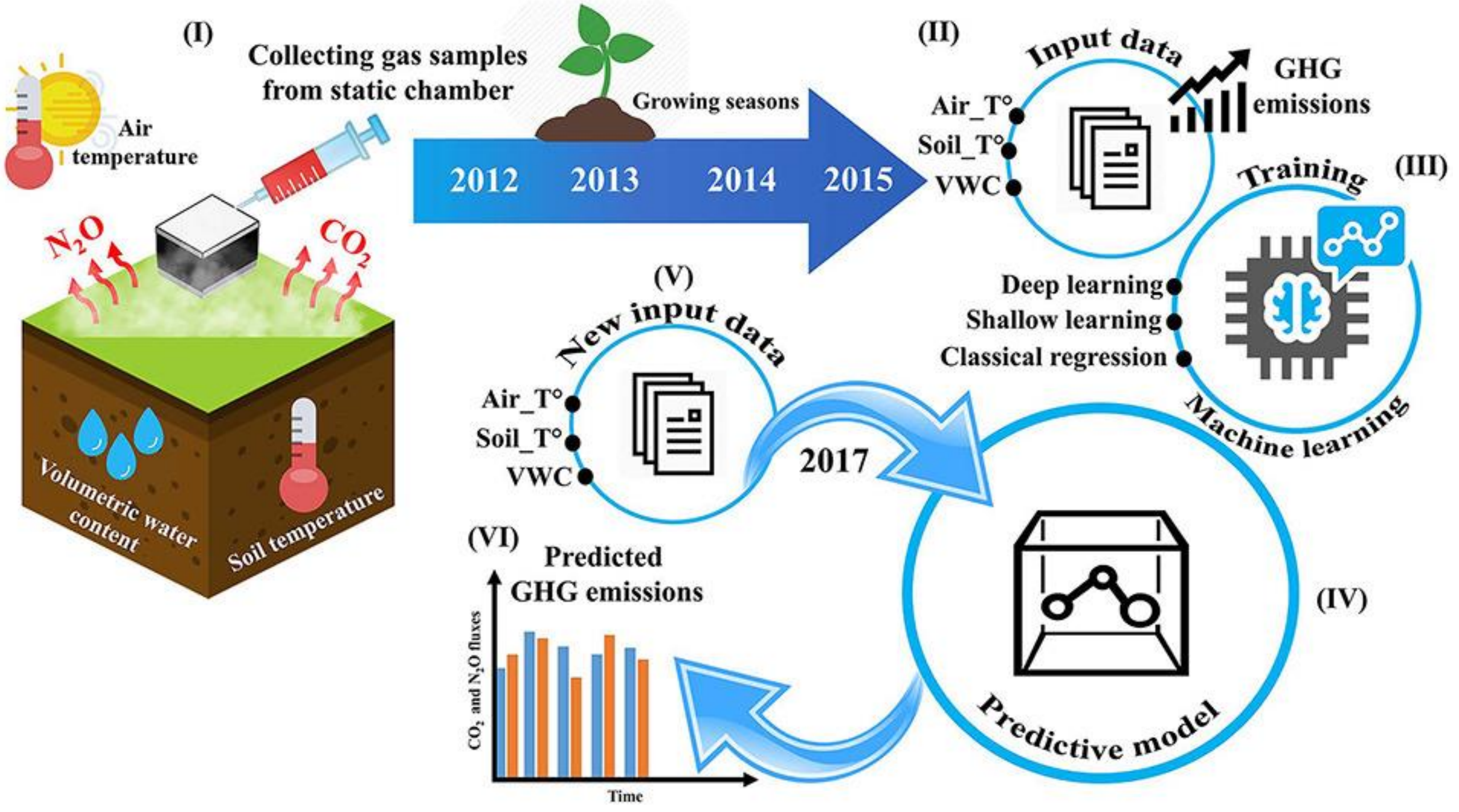
- **Use of machine learning algorithms to optimize irrigation systems, improve water use efficiency, and reduce water loss**

- **Monitoring agricultural productivity and integration with advanced AI**



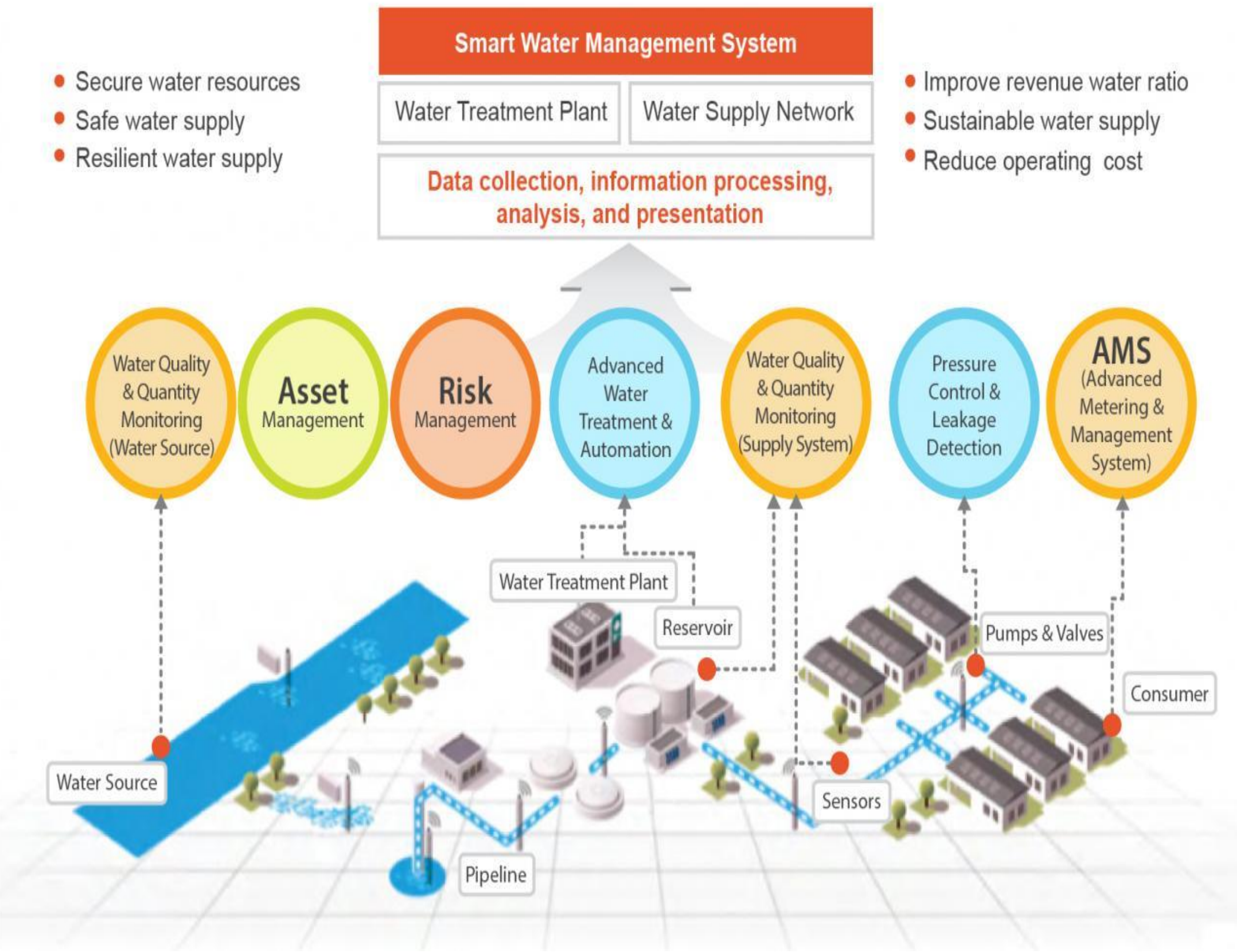
Step-by-step process to develop a predictive machine learning model:

- Defining the problem statement
- Collection and preparation of model data
- Selection of the best prediction or classification models according to the result needed.
- Training the models on the set of input parameters
- Evaluation of the models
- Fine tuning of the models
- Deploying the model result to the various stakeholders



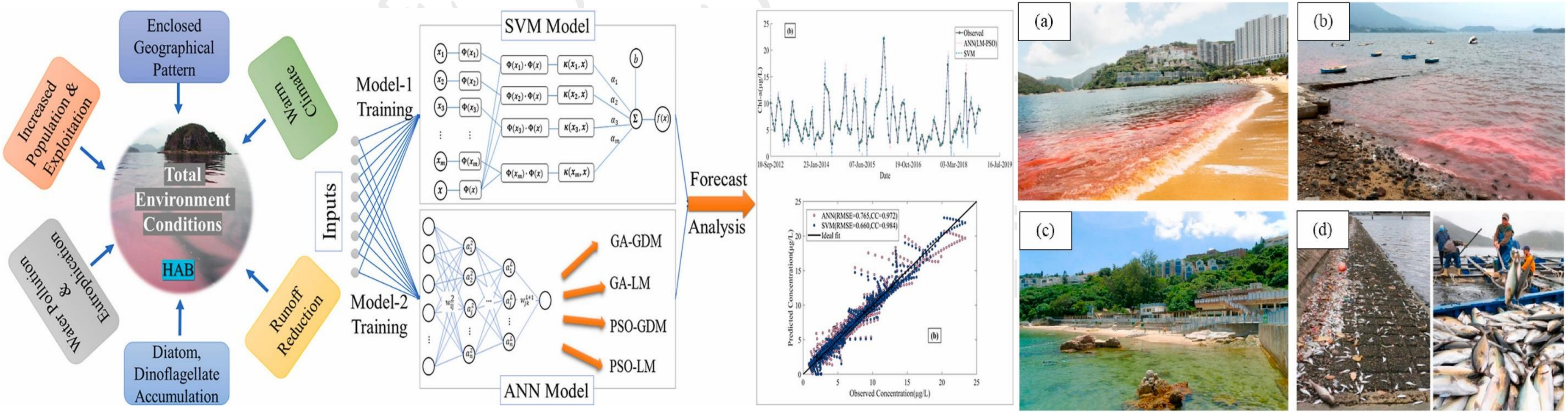
Machine learning plays a significant role in the development of smart water systems.

- **Predictive maintenance:** Machine learning algorithms can be used to predict the likelihood of a failure in water distribution systems.
- **Water demand forecasting:** Machine learning algorithms can be used to analyze historical water usage patterns and make predictions about future demand.
- **Water quality monitoring:** Machine learning algorithms can be used to identify patterns in water quality data, detect anomalies, and provide early warnings.
- **Leak detection:** Machine learning algorithms can be used to detect leaks in water distribution networks, by analyzing pressure and flow data.



Application of Machine learning in environment and water quality

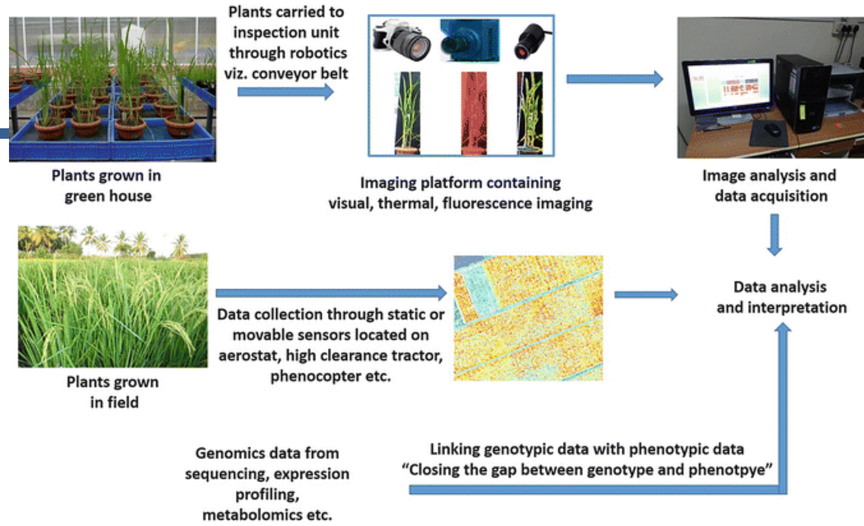
- **Water resource management:** Machine learning can be used to optimize water resource management by predicting water demand, improving the efficiency of water distribution systems, and reducing water loss due to leaks and theft.
- **Machine learning models** can be used to monitor environmental conditions such as air quality, land use, and land cover changes. **This information can be used to inform environmental policy and management decisions.**

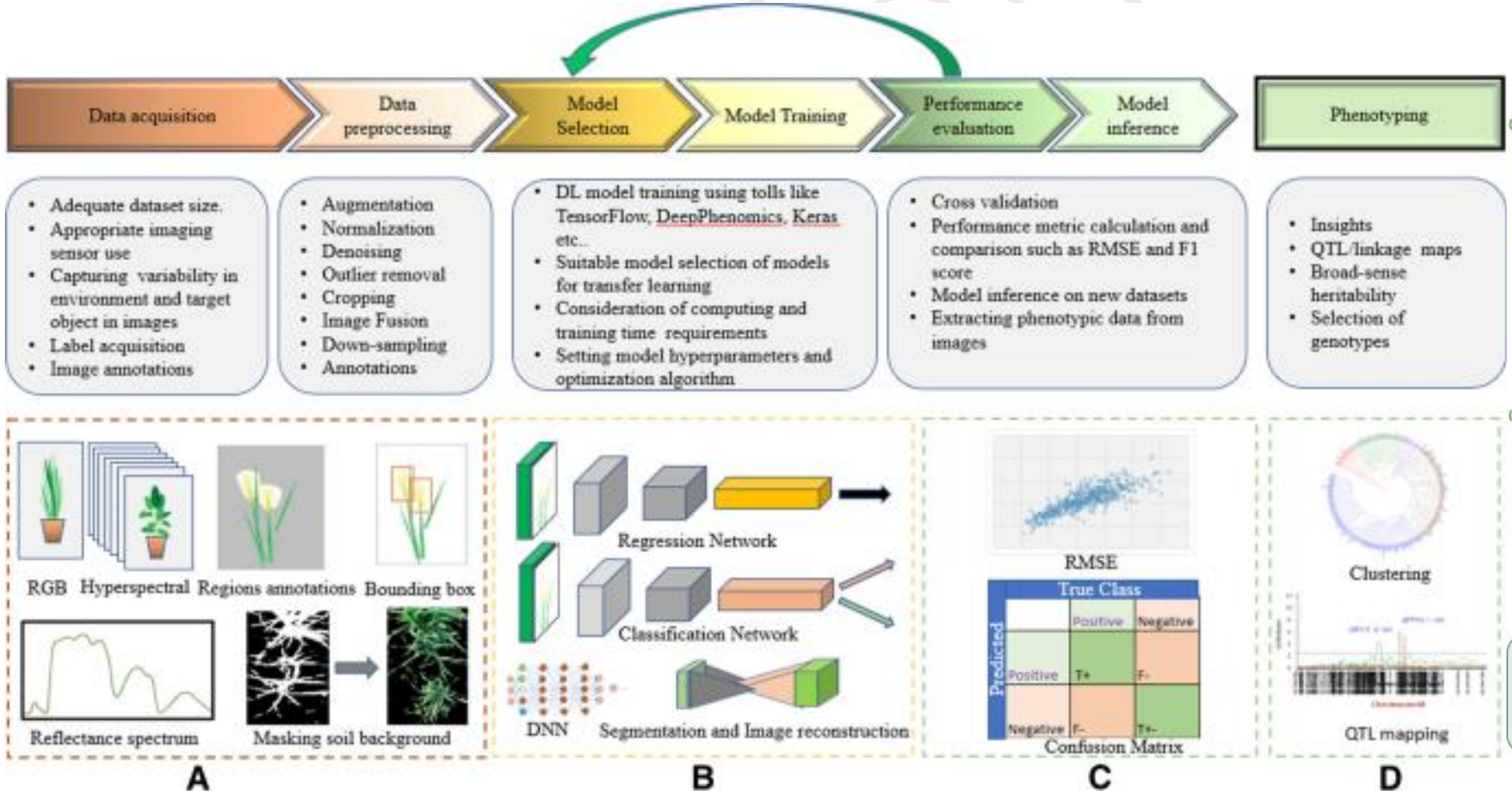


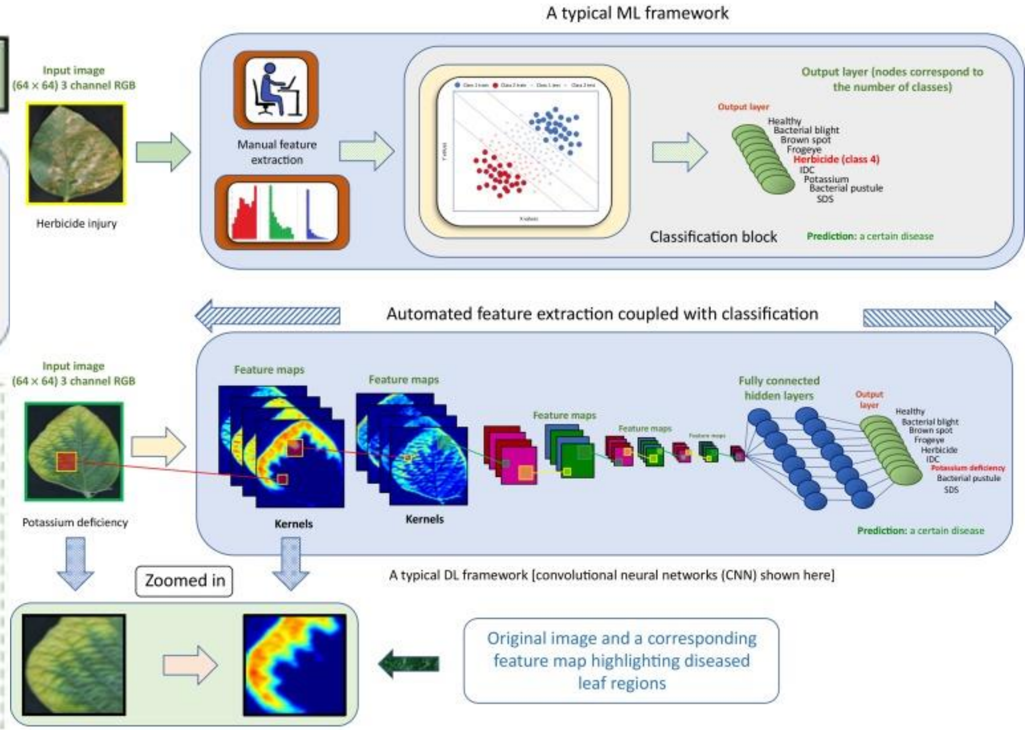
Machine Learning in plant science

The various application consists of:

Plant classification and identification, Crop yield prediction, crop Disease diagnosis, Climate change impact analysis and Precision agriculture

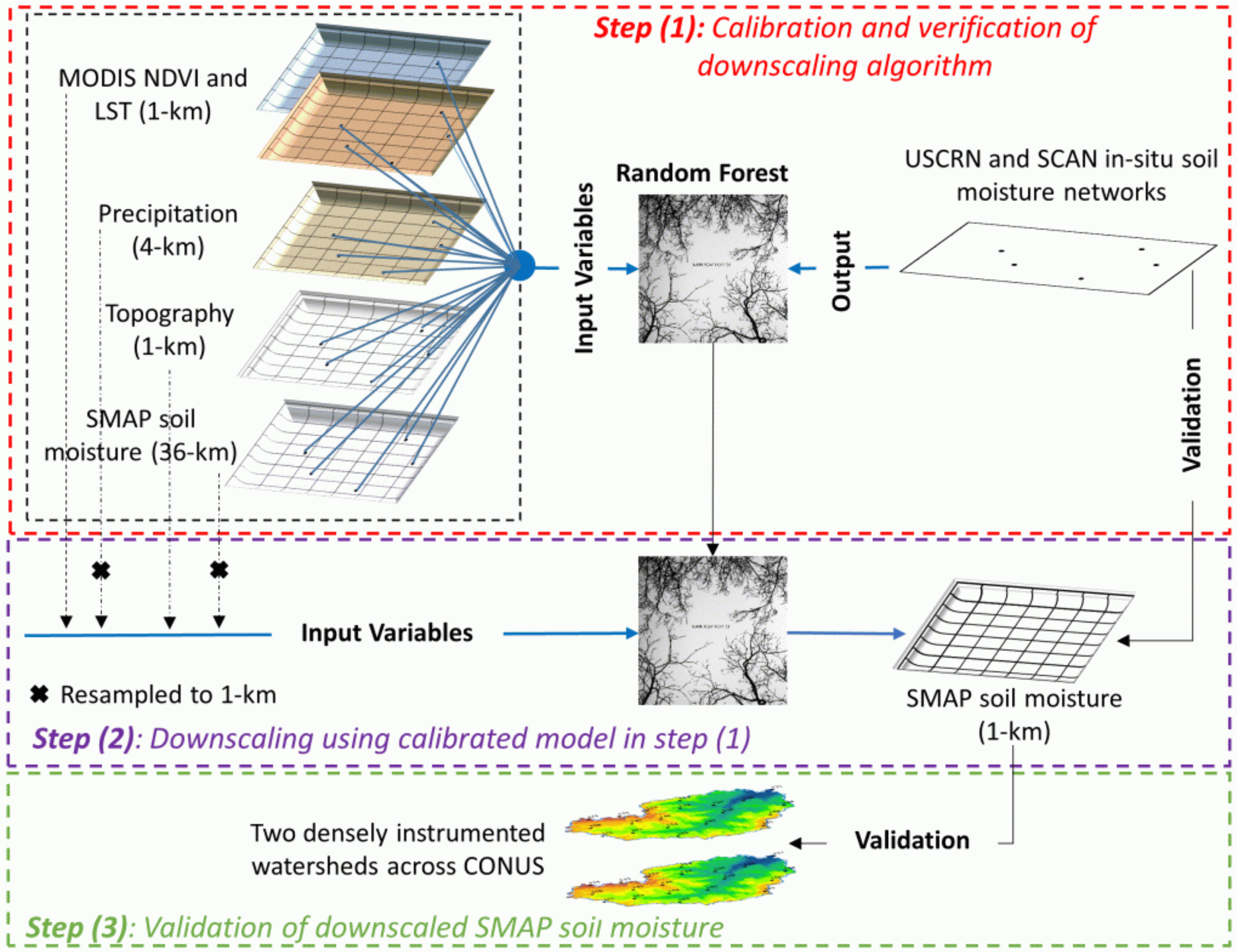






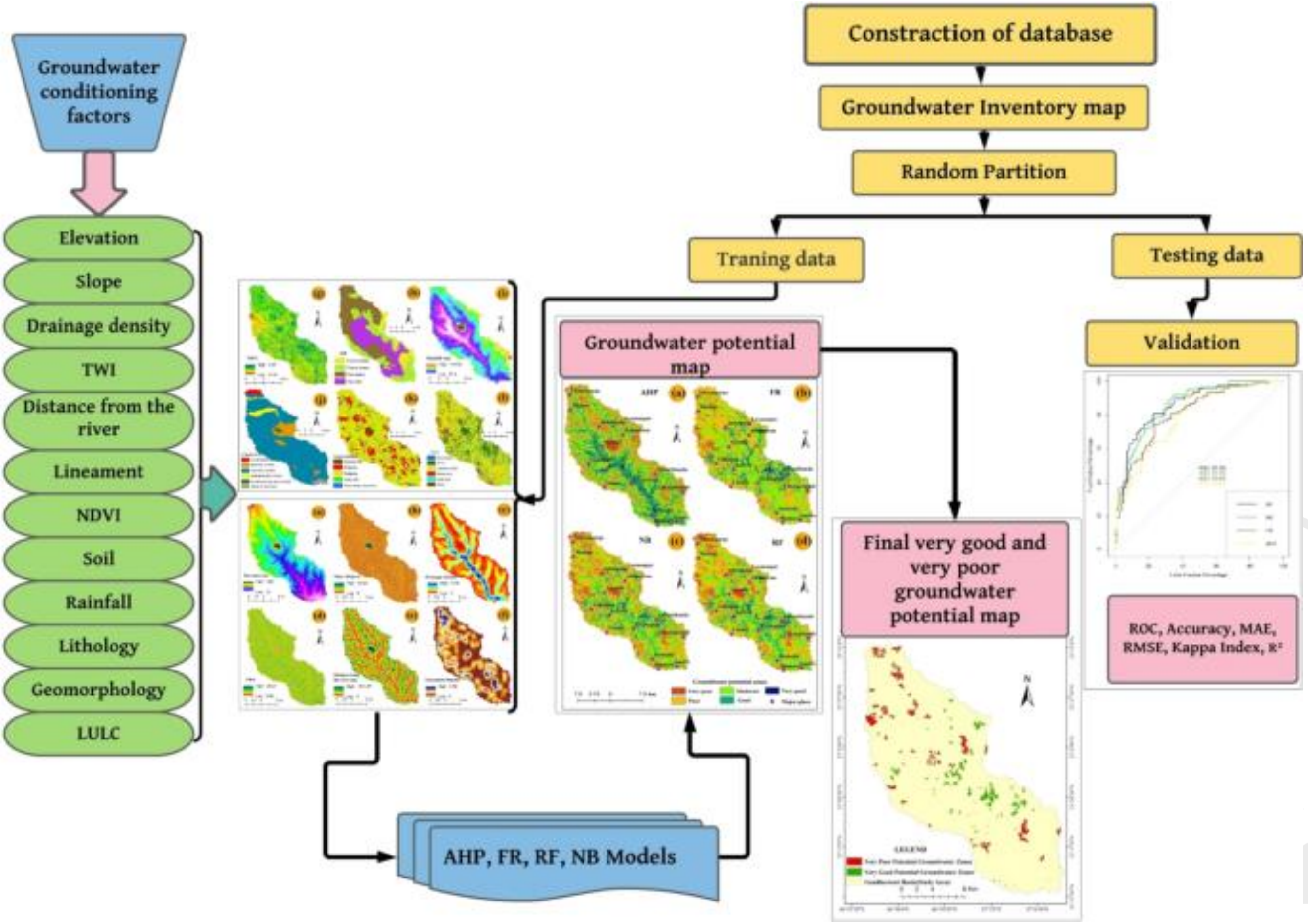
Trends in Plant Science

Soil moisture prediction using ML



- **Remotely sensed soil moisture satellite data provide an unprecedented information about the soil moisture across spatial and temporal scales, which is logistically unachievable from in situ observation networks.**
- **SMAP (Soil Moisture Active Passive) is one of those satellites that provides soil moisture data at top 5 cm soil layer using brightness temperature on the 36-km grid cell.**
- **SMAP soil moisture observation has a decent spatial resolution for global and continental scale applications, it cannot be used directly for regional or local studies, such as agriculture and drought monitoring, irrigation management and planning, flood forecasting, crop production and water resources management.**
- **Hence, the downscaled soil moisture product must be validated against in situ soil moisture sensors evenly distributed over any region.**

Groundwater Potential by ML techniques



Data collection: Collect data on geological, hydrological, and other relevant factors that impact groundwater potential.

Data pre-processing: This will involve removing outliers, filling in missing values, and normalizing the data.

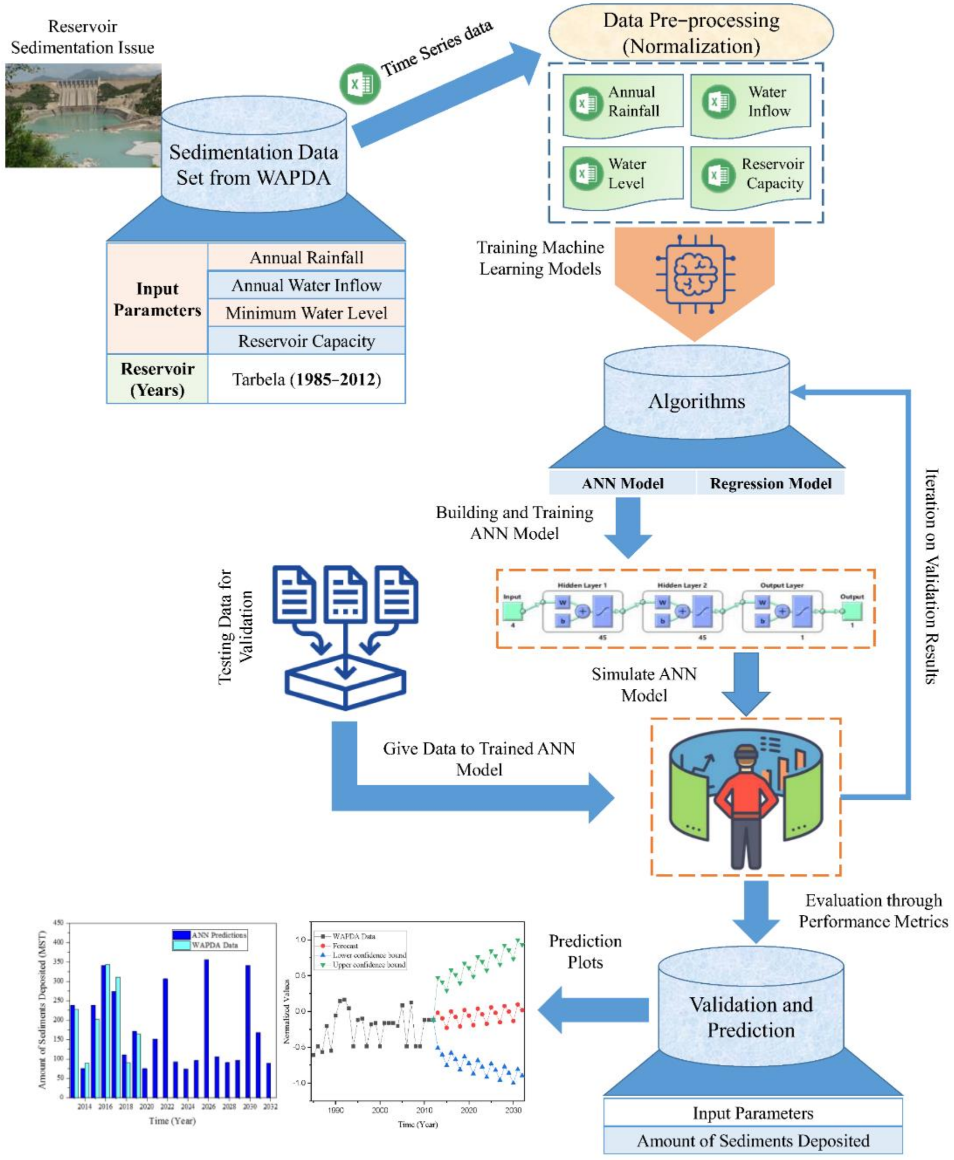
Feature selection: Identify the most important features (i.e. variables) that impact groundwater potential. This can involve statistical analysis and feature importance measures.

Model selection: Choose an appropriate machine learning model for groundwater potential delineation. This could be a simple decision tree model, a more complex artificial neural network, or a random forest.

Model training: Train the selected machine learning model using the pre-processed data and identified features.

Model evaluation: Evaluate the trained model by comparing its predictions with actual groundwater data.

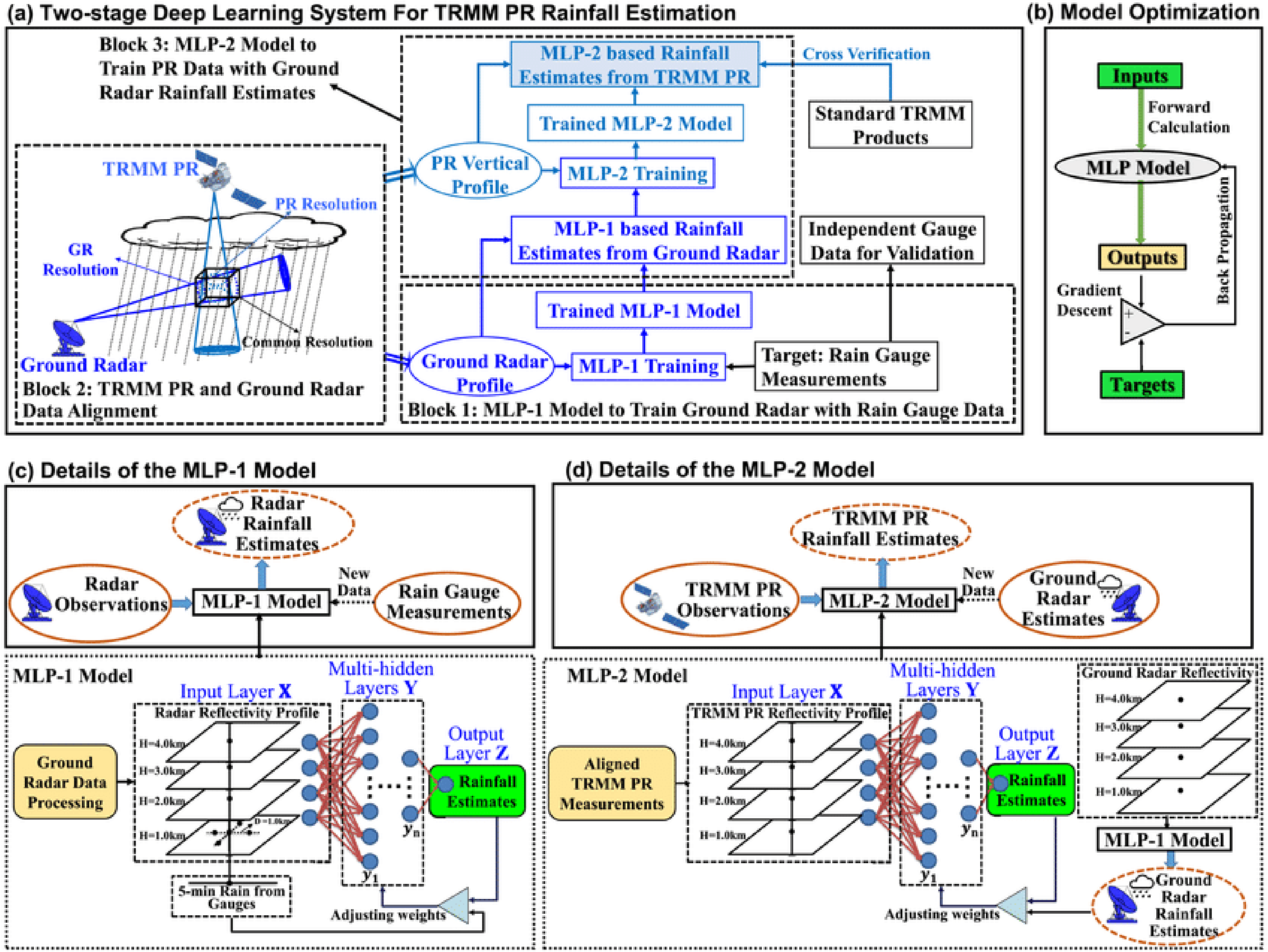
- **Validation and refinement:** Validate the generated groundwater potential map by comparing it with actual groundwater data and make any necessary modifications.



ML in Suspended sediments calc.

1. Estimation of time series data consisting of Annual rainfall, Water inflow, level and Reservoir capacity.
2. Omission of the outliers in the collected data by various statistical methods.
3. Selection of Machine learning models such as ANN or any regression models.
4. Training the datasets on the set of input parameters.
5. Simulation of the model and performance check of the ML models based on validation statistics.
6. Plotting the models result for observing the suspended sediments in the reservoir upstream.

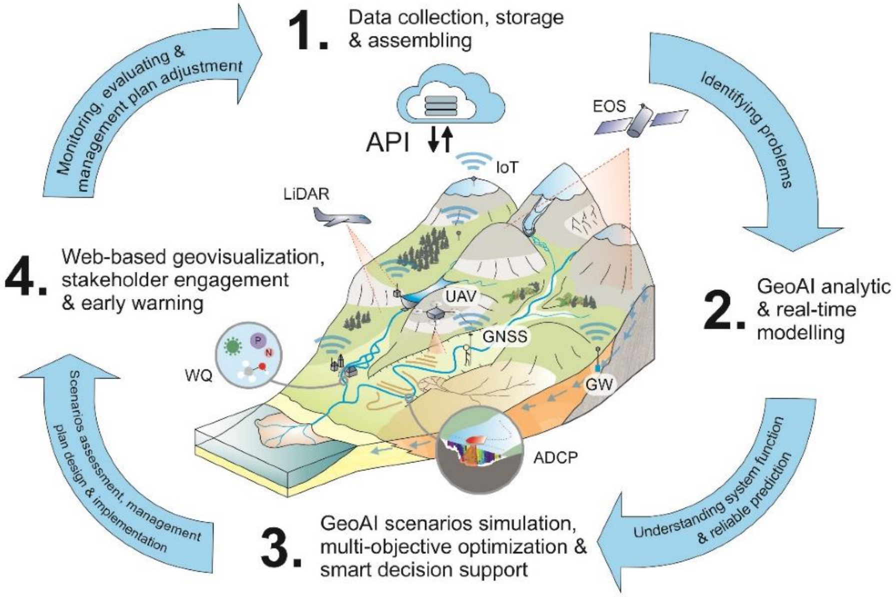
Precipitation cal. By ML



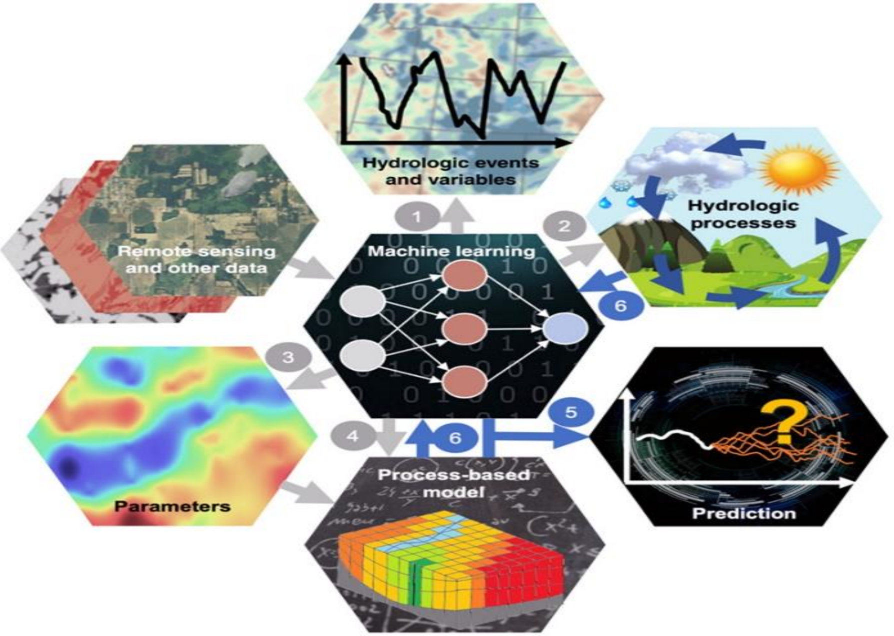
- This system develops a deep learning mechanism to link between point-wise rain gauge measurements, ground-based, and spaceborne radar reflectivity observations.
- Two neural network models are designed to construct a hybrid rainfall system, where the ground radar is used to bridge the scale gaps between rain gauge and satellite.
- The first model is trained for ground radar using rain gauge data as target labels, whereas the second model is for spaceborne Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) using ground radar estimates as training labels
- Validation using independent data against the standard precipitation products, demonstrates the promising performance and generality of this innovative rainfall algorithm.

Integrated Watershed management using ML

- Integrated watershed management is a holistic approach to managing a watershed, which is an area of land that drains the water, sediment, and dissolved materials to a common outlet such as a river, lake, or sea.
- The approach integrates various aspects of water management, including hydrology, geology, biology, and socio-economic factors, to sustainably manage the watershed's resources and mitigate water-related challenges such as flooding, soil erosion, and water scarcity.
- The goal of integrated watershed management is to balance human needs with the needs of the ecosystem to ensure the long-term health and productivity of the watershed.



Geospatial artificial intelligence (geoAI) is an emerging scientific discipline that combines innovations in spatial science, artificial intelligence methods in machine learning (e.g., deep learning), data mining, and high-performance computing to extract knowledge from spatial big data.



AI ON WATER QUALITY

- Artificial intelligence is recently used to enhance remote monitoring of water bodies by University of Stirling :–
- A new algorithm was developed
- Known as the 'meta-learning' method was developed to analyse the data directly from satellite sensors thus making it easier for coastal zone, environmental and industry managers to monitor issues such as harmful algal blooms (HABs) and possible toxicity in shellfish and finfish.

Source : University of Stirling. "Artificial intelligence to monitor water quality more effectively." ScienceDaily. www.sciencedaily.com/releases/2021/05/210504112514.htm (accessed May 8, 2021).

FLOOD SUSCEPTIBILITY

- Flood susceptibility maps are crucial steps for decision-makers to prevent and manage disasters which helps to identify the vulnerable regions.
- Plenty of studies have used machine learning models to produce reliable susceptibility maps.
- A novel method was developed to use the deep learning technique of LSTM to predict flood susceptibility
- Appropriate feature engineering method with LSTM was integrated to predict flood susceptibility.
- As a result not only temporal but also spatial accuracy of prediction get improved.

Source : Fang, Zhice, Yi Wang, Ling Peng, and Haoyuan Hong. "Predicting flood susceptibility using LSTM neural networks." Journal of Hydrology 594 (2021): 125734

- LSTM (Long Short-Term Memory) is a recurrent neural network (RNN) architecture widely used in D

- **LSTM** is well-suited for sequence prediction tasks and excels in capturing long-term dependencies.

- Its applications extend to tasks involving time series and sequences.

- LSTM’s strength lies in its ability to grasp the order dependence crucial for solving intricate problems, such as machine translation and speech recognition.

Five AI solutions to reduce flood risk

- In recent decades, floods have caused extensive loss of life and property. In addition, the relentless rains in Bengaluru have worsened the already terrible traffic conditions in the city.
- The most frequent and expensive natural hazards worldwide are floods. Resulting disasters resulted in 21,700 losses between 1980 and 2014, with a total loss of US$ 4,200 billion, 40% attributable to overflow, and approximately 226,200 fatalities (excluding famine). The proportion of foods and mass movements rose to 50%, 47%, and 45% in 2016, 2017, and 2018, respectively. Food-related losses of life and property are enormous in developing nations. The most vulnerable areas are when monitoring floods so that the authorities can create appropriate solutions. The best course of action is to warn people as soon as possible before the damage takes place, giving them enough time to evacuate both themselves and their property.
- Many researchers worldwide have developed AI solutions for flood prevention and management. Moreover, many people are working hard to achieve it. Here are five AI solutions from researchers worldwide for preventing and dealing with floods.

Five AI solutions to reduce flood risk.............

- Likewise researchers from England described a sensor network with Gumstix sensor nodes for flood prediction in 2006. 13 nodes made up the tested system, which ran along a river for one kilometre. The emphasis was on the flood event of a river, and the sensor network solution included two communication levels, four node types, and a variety of sensor types. This approach was similar to MIT researchers in 2008, who presented an architecture for predictive environmental sensor networks over large geographic areas. In addition, they discussed a flood prediction algorithm that had been functionally tested experimentally with radio antenna towers.
- Later in 2018, Chinese researchers used smart cities with a lot of data to predict flood disasters in cities accurately. Using historical hydrological data, they made a new flood protection system called NFDDSS to help people make decisions. The focus was on how the water level prediction model based on a classification and regression tree worked with time and space. The authors say that it is possible to predict water levels in 1–6 h accurately. However, because this method relies heavily on having large amounts of historical data available in smart cities, it is most accurate after flooding has already happened. So, this method might not accurately predict flood disasters in new areas.
- Furthermore in 2019, a group of researchers from Australia, South Korea, and France reviewed the research on how we can use IoT-based sensors and computer vision to monitor and map floods. They showed how computer vision techniques and IoT sensor approaches are in the literature for real-time flood monitoring, flood modelling, mapping, and early warning systems, such as estimating the water level. In particular, they suggested ways computer vision and Internet of Things (IoT) sensor technologies manage coastal lagoons.

Five AI solutions to reduce flood risk.............

- The researchers from Spain showed an early sound-based system for detecting water leaks. The system comes with a software program that lets you measure water levels, fluid types, sensor batteries, and general network information from a distance. The structure is a control centre for coordinating and processing data in the wireless (IEEE 802.15.4 technology) network and five flood sensors with built-in radio modules that can communicate over the Internet or 2G/3G/4G through the control centre and are therefore accessible through an external network.
- Similarly, Malaysian researchers investigated the effectiveness of the Internet of Things (IoT) in disaster management applications. The authors propose an IoT technology that collects water level and flows data using wireless sensor networks (WSNs), cameras, mobile phones, and weather stations as crucial components. The weather station records temperature, wind speed, and direction—Cameras record images of environmental data. Wifi and Zigbee transmit collected data to the middleware layer for processing and analysis in the network layer. The middleware then performs data management functions, such as processing the collected data and presenting essential information in the form of a flood map, such as flood extent, time, and location. Users can access information from their smartphones and receive push notifications when an emergency occurs.

EAI Endorsed Transactions on Internet of Things Flood Monitoring and Early Warning Systems -An IoT Based Perspective

- One of the most frequently occurring calamities around the world is a flood. For flood prone areas or countries, an essential part of their governance is flood management.
- The necessity to continuously review and analyze the adverse or ambient environmental conditions in real-time demands developing a monitoring system so that floods could be detected beforehand.
- This paper discusses different **Internet of Things (IoT) based techniques and applications implemented for efficient flood monitoring and an early warning system and it is observed that in the future, the combination of IoT and synthetic aperture radar (SAR) data may be helpful to develop robust and secure flood monitoring and early warning system that provides effective and efficient mapping during natural disasters.**
- The emerging technology in the discipline of computing is IoT, an embedded system that enables devices to gather real-time data to further store it in computational devices using wireless sensor networks (WSN) for further processing.
- The IoT-based projects that can help collect data from sensors are an added advantage for researchers to explore in providing better services to people.
- These systems can be integrated with cloud computing and analyzing platforms. Researchers recently have focussed on mathematical modelling-based flood prediction schemes rather than physical parametric-based flood prediction. The new methodologies explore the algorithmic approaches. There have been many systems proposed based on analog technology to web-based and now using mobile applications. Further, alert systems have been designed using web-based applications that gather processed data by Arduino Uno Microcontroller which is received from ultrasonic and rain sensors.
- Additionally, the machine learning (ML) based embedded systems can **measure different atmospheric conditions such as temperature, moisture, and rains to forecast floods by analyzing varying trends in climatic changes**.

SNOW DEPTH

- Purpose : "Accurate high spatial resolution snow depth mapping in arid and semi-arid regions is of great importance for snow disaster assessment and hydrological modelling. ". But due to the complex topography and low spatial-resolution microwave remote-sensing data, the existing snow depth datasets have large errors and uncertainty, and actual spatiotemporal heterogeneity of snow depth cannot be effectively detected.
- Inputs : The (Fengyun-3 Microwave Radiation Imager) FY-3 MWRI data were downscaled to 500 m resolution to match Moderate-resolution Imaging Spectroradiometer (MODIS) snow cover, meteorological and geographic data.
- Output : Downscaled snow depth data
- Model Used : Deep Learning
- Conclusion : "Downscaled snow depth could provide more detailed information in spatial distribution, which has been used to analyze the decrease of retrieval accuracy by various topography factors."... Zhu et.al.(2021).
- **Source** : Zhu, Linglong, Yonghong Zhang, Jiangeng Wang, Wei Tian, Qi Liu, Guangyi Ma, Xi Kan, and Ya Chu. "Downscaling Snow Depth Mapping by Fusion of Microwave and Optical Remote-Sensing Data Based on Deep Learning." Remote Sensing 13, no. 4 (2021): 584.

CONCLUSION

- Six tenable examples of the application of Artificial Intelligence on water resource problems were discussed.
- In all the studies, the most common observation was the noticeable improvement of the accuracy in the estimations from the deep learning model compared to the conventional numerical frameworks.
- The capacity to adapt from the input data is the main advantage of using AI
- But data requirement is also high.
- Model developed with fewer data is as accurate as linear models
- If very few data or examples are provided to the model for learning the inherent relationships that exist in between the input and output variables of the model AI based models will fail miserably.
- In case of water resource problems data availability is the main constraint.
- So intelligent application of AI based models hybridizing with another model may solve the problems, but it may also compromise the adaptable capacity of AI models.

To summarize:

- AI provides tools and techniques to solve the water crisis.
- We deploy low-cost AI-powered sensors everywhere to monitor and manage water.
- People are fighting for basic necessity.
- We should start building these AI-based intelligent machines to solve global issues.
- AI has all the answers, we just need to use it in the right way to solve this water scarcity problem.
- Researchers are working towards a reliable, sustainable, and resilient water infrastructure with the assistance of artificial intelligence.

CONCLUDING REMARKS.....

- Water Management..............Needs
- Identify the hydrological boundary of the study area
- Assessment of Water Resources in the Area
- Demand/Supply/Gap
- If possible Try to make an assessment of Climate Change-Impact
- Identify the present Demand-Supply Gap and the Future of Sustainability
- Try to identify all possible sources.......
- Demand Management Options...its Viability/Affordability
- Try to identify leakages/losses...............Try to reduce them
- Rainwater Harvesting: Implementation
- Water Conservation
- Local Water Bodies: Identification and their revival
- Land-use change Study its impact: Try to increase the green zones
- Efforts should be made to work for sustainable solutions
- Plan judicious use of any water management model for sustainable development
- Use various AI models to train models with conventional models


Thank You!