# 1 Introduction and Research Problem

The increasing demand for identifying suitable living environments due to climate change, pollution, and population growth has necessitated the use of advanced technological systems to assess environmental viability. Traditional environmental monitoring methods are often limited by human access, safety risks, and incomplete data collection. Remote areas, especially in rural or uninhabited regions, lack continuous monitoring infrastructure.

Therefore, autonomous systems capable of real-time, accurate data gathering are essential for modern environmental assessment. This research proposes an autonomous, sensor-based robotic system designed to evaluate the environmental suitability of rural and uninhabited areas.

# 2 Nature of the Solution

The proposed solution is an autonomous, sensor-based robotic system designed to explore rural or uninhabited areas and assess environmental suitability for human living. The system consists of two main components:

1. **Primary Robot:** Responsible for environmental data collection (Water, Soil, Air). It operates within a pre-defined range (30 meters) and autonomously returns to base if the signal is lost.

2. **Sub-Robot:** Acts as a network range extender and backup unit. It deploys when the main robot reaches its connectivity limit, moving up to 20 meters to function as a network access point or switch.

In case of a complete network failure, the sub-robot stores the data locally and forwards it once the connection is reestablished. This solution integrates real-time sensing, wireless networking, automatic data backup, and distance-based control.

# 3 Domain Expertise and Requirements

The development of this system requires specialized domain expertise:

- **Robotics Engineering:** Essential for autonomous navigation, motor control, obstacle avoidance, and base return mechanisms.

- **Embedded Systems:** Required for integrating sensors and actuators using microcontroller programming.

- **Environmental Science:** Needed to interpret parameters such as pH, turbidity, dissolved oxygen, soil moisture, and air quality ($CO_2$, PM2.5).

- **Wireless Networking:** Expertise in IoT protocols, RF, Wi-Fi, mesh networking, and failover data transmission is critical for the master-slave robot communication.

# 4 Project Objectives and Technical Implementation

*The following subsections detail the individual responsibilities, objectives, and technical implementations for each team member.*

## 4.1 Water and Humidity Quality Analysis

**Objectives:**

- Connect and calibrate water quality sensors (pH, turbidity, heavy metal detection) and humidity sensors.
- Link sensor data to a user interface/dashboard for real-time monitoring.

**Technical Implementation:** Networking is used to transmit sensor data from the main robot to a remote server using lightweight communication protocols like MQTT or HTTP over Wi-Fi or LoRa. In areas with poor connectivity, buffered transmission is implemented to store and forward data without loss. Network-aware firmware ensures that alerts are triggered instantly when unsafe water conditions are detected.

## 4.2 Soil and Air Quality Analysis

**Objectives:**

- Integrate soil sensors (pH, moisture, temperature) and air sensors ($CO_2$, CO, $O_2$, PM2.5).
- Analyze environmental suitability for agriculture and human habitation using AI.

**Technical Implementation:** Data is collected and transmitted wirelessly from the robot to a central monitoring system using protocols such as LoRaWAN or Wi-Fi to provide long-range, low-power communication. The data is visualized through a centralized web dashboard or mobile app. Redundant communication ensures reliable data flow even in low-signal environments.

## 4.3 Robot Communication & Offline Data Sync

**Objectives:**

- Enable simultaneous data transmission to both the server and the sub-robot.
- Configure the sub-robot to store sensor data locally as a backup.
- Implement a detection system for server connection loss and synchronize data once restored.

**Technical Implementation:** This function uses point-to-point wireless communication between the main robot and the sub-robot through protocols such as RF or LoRa. Sensor data is transmitted in parallel. If the network link fails, the sub-robot securely stores the data using compressed and encrypted formats. Once the main system regains connection, the sub-robot automatically syncs the data back to the server to prevent any loss or duplication.

### 4.4 Robot Controlling & Self-Diagnosing Modules

**Objectives:**

- Implement a distance-tracking system (GPS/Mapping) with a 30-meter safe range limit.
- Enable the sub-robot to move forward and act as a Wi-Fi switch/Access Point, extending range to 50 meters.
- Develop an autonomous return-to-base system upon signal loss.

**Technical Implementation:** Embedded microcontrollers communicate via UART, I2C, and Wi-Fi for distance mapping, system diagnostics, and control commands. A mesh or point-to-point network connection allows the sub-robot to act as a dynamic access point (AP). The return-to-base function is triggered automatically upon signal loss or low connectivity, ensuring autonomous navigation safety.