From Trash to Tech: Using AI and Drone Technology to Tackle Environmental Challenges

Janakpurdham's Waste Crisis

Janakpurdham is a sub-metropolitan city located in Dhanusha district of Nepal. The city has a rich cultural history that goes back to hindu mythology symbolized by the famous Janaki Temple. The city hosts various festivals throughout the year, including the Ram Navami, Vivah Panchami, chhath puja and holi where thousands of people gather to celebrate the vibrant culture and tradition. Additionally, Janakpur is home to several historical sites, landmarks and art that showcase the rich heritage of the region. In addition to its religious importance, Janakpur is one of the cities of Nepal where urbanization has taken off at a rapid pace. The city has witnessed significant infrastructural development, with modern amenities and facilities being introduced to cater to the growing population.

Despite its significance as a pilgrimage site, the city has been dealing with the pressing issue of unregulated waste disposal, resulting in environmental degradation. An analysis of available datasets revealed alarming amounts of solid waste accumulation in various key areas, including barren lands, railway trails, and roads. This waste accumulation poses a severe threat to the health and well-being of the residents. Various news sources have reported that locals have voiced concerns about the ongoing waste issue time and again, yet waste continues to affect the surroundings, posing a persistent challenge to the community and its environmental well-being. Realizing the challenge of waste management, an innovative approach for waste monitoring and observation was developed using drone imagery and artificial intelligence(AI).

Fig: haphazard solid waste disposal in Janakpur

Research and Collaboration for Sustainable Solutions

After the problem identification, we engaged in extensive review of literature; studying various related articles and papers. Through our research, we discovered that we could successfully implement AI technologies to tackle waste accumulation along with valuable insights and best practices. Additionally, we reached out to experts in the field and collaborated closely to gain a deeper understanding of the challenges and potential solutions. We expanded technical knowledge by working under mentorship of seasoned experts to develop a comprehensive plan that integrates drone imagery and AI.

A very high resolution data was captured using a drone. The theorized AI solution was modeled to identify patterns and trends, allowing for targeted interventions, and improved waste management practices.

Fig: Labeling areas with waste

From Data Collection to Analysis

The team first collected images using a hybrid VTOL drone - Wingtra One Gen 2.The mapping crew processed the images captured by the drone using PIX4D software to produce high resolution orthophoto, and digital surface models. The drone-captured images had a high spatial resolution, approximately 8 cm, ensuring detailed and precise representation of the land of interest.

With the available imagery, we conducted experiments utilizing a range of tools and methodologies encompassing both supervised and unsupervised learning. In the context of unsupervised learning, we employed methods such as k-means clustering, thresholding, and contouring. The resulting outputs were rendered unusable due to the similarity in pixel values between buildings, roads and waste, causing them to be grouped together in the same cluster.

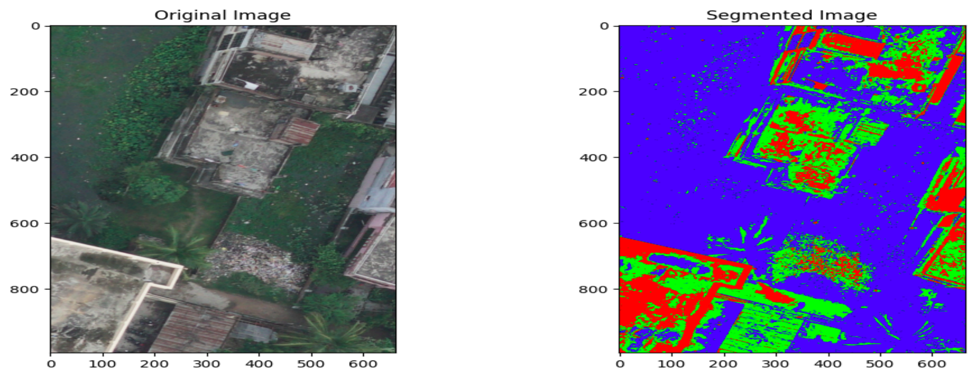

Fig : Result after clustering

As a result of these issues, we transitioned to supervised learning, which required us to annotate the data and generate a corresponding mask. A Tiff image of a specific region in Janakpurdham, specifically ward number 7 was taken, and then a mask was generated. The dataset was generated by annotating waste regions using Quantum GIS (QGIS). This annotation process involved the precise labeling of waste sites within the specified area of study on the drone-captured images. The annotations established a ground truth dataset that accurately represents the spatial distribution of garbage, which was for training and validation purposes.

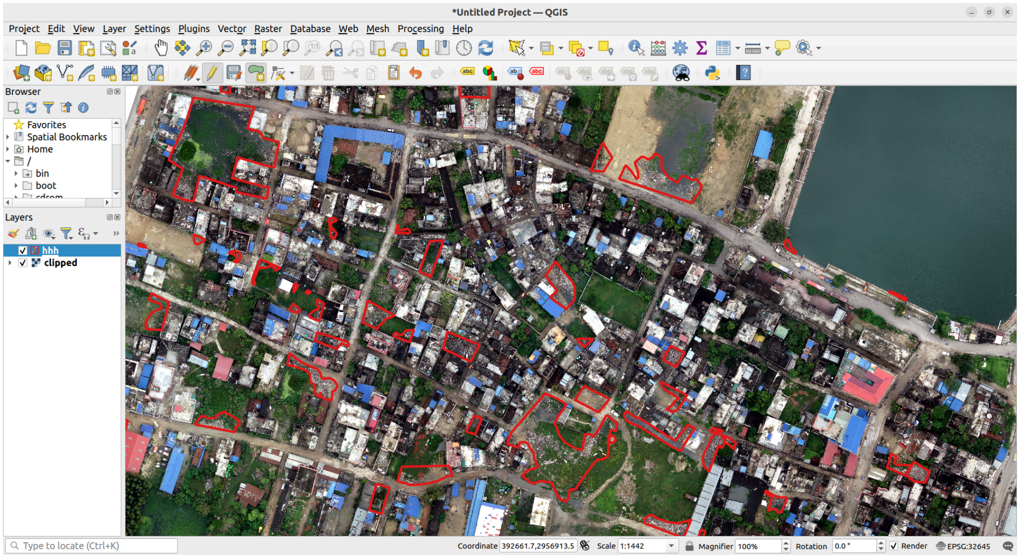

Fig : Annotating image in QGIS

Following the annotation process, masks were generated for the annotated images. These masks served as binary representations of waste and non-waste areas within the images. The annotated images were then divided into patches of size 256 by 256 pixels to facilitate the training process.

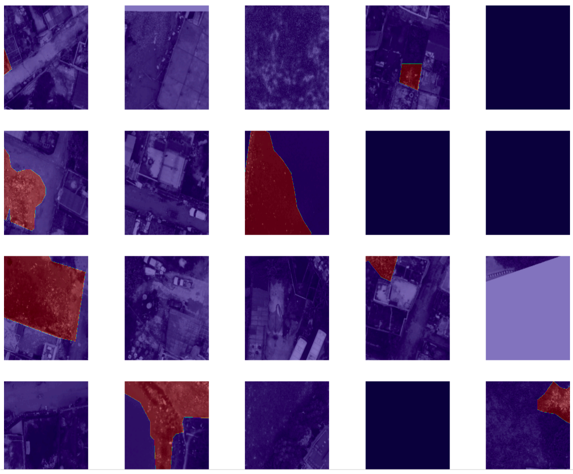

Fig: 256*256 images and mask

Building Effective Waste Detection Models

After a few rounds of experimentation, U-Net segmentation_models architecture was selected as suitable for our purpose due to its demonstrated effectiveness in accurately segmenting similar data.

The U-Net design is distinguished by its encoder-decoder structure, in which the encoding path uses a sequence of convolutional layers to extract features, while the decoding path employs transposed convolutions to do upsampling. The segmentation_models library was used to smoothly configure the U-Net architecture, incorporating the ResNet34 backbone network. This functionality offered a wide range of feature extraction architectures for our U-Net model, improving its capacity to catch complex patterns that are important for waste detection in images acquired by UAVs. Leveraging the library's intuitive API, the model's architecture, loss functions, and optimization parameters were defined. Further, class weight was also introduced to handle the class imbalance problem resulting in more accurate prediction, , particularly in scenarios where waste patches were less prevalent in the dataset.

Achievements and Future Directions

The model was trained for 100 epochs, saving the model after every epoch. This approach ensures that the model captures the most accurate and up-to-date information, allowing for continuous improvement and optimization. Additionally, by saving the model after every epoch, it becomes easier to track and analyze the training progress, facilitating further enhancements to the waste detection model. We chose the best model with the highest IOU, and lowest loss for deployment in our waste detection system. It has a training IOU of 0.7538, a training loss of 0.3116, a validation IOU of 0.7238, and a validation loss of 0.2833.

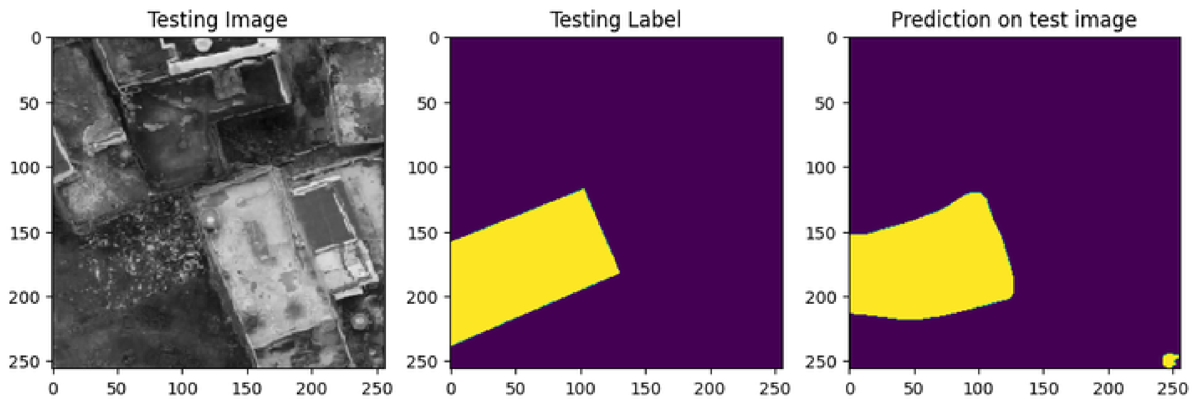

Fig: Testing image, testing labe and prediction on test image

Another region of Janakpur was taken and the model was tested on it. For the testing purpose, the selected area was converted into tiles of 256×256 using the gdal2tiles package. Each tile was fitted into the model and the solid waste accumulated areas were highlighted.

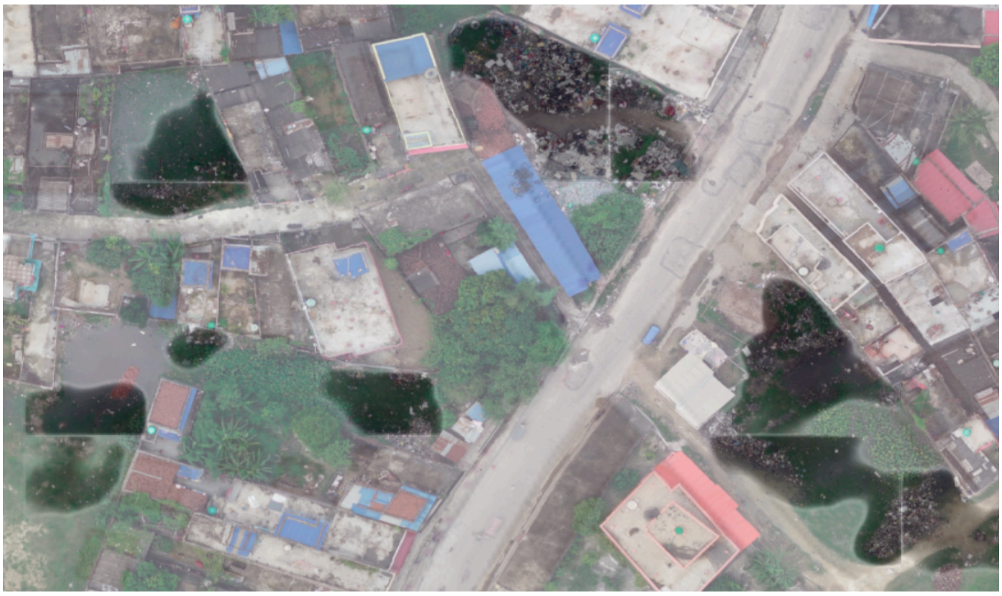

Fig: Output of trained model

The solid waste detection model showcased opportunities for real-world impact using GeoAI. Furthering this project, a system capable of detecting and classifying different types of solid waste by providing UAV imagery can be drawn. It allows for immediate detection of any potential issues and prompt action to be taken. By analyzing trends, we can also predict future waste accumulation patterns. This can greatly improve the efficiency and effectiveness of waste management operations. Integrating the model with Internet of Things (IoT) devices and remote sensing technologies enables real-time monitoring, which broadens the use cases of our waste detection model.