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Determination of mortar strength using stone dust as a partially replaced material for cement and sand

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Abstract. Mortar is a masonry product which is matrix of concrete. It consists of binder and fine aggregate and moreover, it is an essential associate in any reinforced structural construction. The strength of mortar is a special concern to the engineer because mortar is responsible to give protection in the outer part of the structure as well as at a brick joint in masonry wall system. The purpose of this research is to investigate the compressive strength and tensile strength of mortar, which are important mechanical properties, by replacing the cement and sand by stone dust. Moreover, to minimize the increasing demand of cement and sand, checking of appropriateness of stone dust as a construction material is necessary to ensure both solid waste minimization and recovery by exchanging stone dust with cement and sand. Stone dust passing by No. 200 sieve, is used as cement replacing material and retained by No. 100 sieve is used for sand replacement. Sand was replaced by stone dust of 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50% by weight of sand while cement was replaced by stone dust of 3%, 5%, and 7% by weight of cement. Test result indicates that, compressive strength of specimen mix with 35% of sand replacing stone dust and 3% of cement replacing stone dust increases 21.33% and 22.76% respectively than the normal mortar specimen at 7 and 28 days while for tensile it increases up to 13.47%. At the end, optimum dose was selected and crack analysis as well as discussion also included.

Keywords: mortar; cement; sand; compressive strength; tensile strength; stone dust; replacement

1. Introduction

Mortar is a product composed of cement and sand that means, when water is mixed in with this product, the cement is activated. Moreover, mortar is used to hold together bricks or stones or other such hardscape components (Aziz 1995).

A complete understanding of mortar and its application is huge to accomplish effective

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execution. When water blended with Portland cement creates pitiless, solid glue that is very unworkable, getting to be hard rapidly. Some Portland cement aids the workability and versatility of the mortar. It likewise gives early quality to the mortar and rates setting.

Sand is the general segment of mortar which provides for its different shade, surface and cohesiveness. Sand must be free of polluting influences, for example, salts, earth or other remote materials. The three key characteristics of sand are particle shape, gradation and void ratio. Sand is mainly used as inert material to give volume in mortar for economy. It offers requisite surface area for film of cementing material to adhere and spread, prevents shrinkage and cracking of mortar. The strength of mortar or concrete is largely affected by the fine aggregates (Sharmin *et al*. 2006). Fine aggregate is usually sand from river (Lohani *et al*. 2012). The main constituents of mortar is sand are mainly natural resources. The presence of very fine materials in excessive quantities influences the performance and properties of fresh and hardened mortar or concrete. In fresh concrete, the workability, air content and bleeding are reduced depending on the amount and composition of the very fine materials in concrete, the cement content and the grading of the sand (Popovics 1979; Kalcheff 1977; Malhotra 1985). In the hardened state, the presence of fine materials can be beneficial for low strength concrete but it may have adverse effects on high strength concrete, since the shrinkage of concrete increases (Ahmed 1989) and its durability is impaired (Popovics 1979).

Alternative material of sand should be explored to mitigate the increasing demand of sand. A considerable amount of dust is produced at the time of stone crushing. On the contrary, they are often considered as a waste in the locality. Saving of natural resources and environment is the essence of any advancement (Reddy 2010).

Numerous attempts have been done since the ancient time and it is still continued to use the waste materials in construction work. Stone dust, fly ash, silica fume, rice husk etc are the waste materials. Exchange of normal sand by stone dust will assist both solid waste minimization and waste recovery (Mahzuz 2011). Several researches have been made (Ahmed 2010; Lohani *et al*. 2012) to discover a proper way of using the stone dust without affecting the strength of cementitious product.

With respect to feasibility in Bangladesh, Masrur (2010) suggested that stone dust is appropriate for medium graded concrete for better performance in terms of strength and economy over normal sand. For Mortar, stone dust is well appropriate to choose it as an alternative of sand. According to Masrur (2010) about 100000 cft of stone dust is generated during stone crushing which is almost equivalent to 1.6 million BDT. With the rapid growth of contraction industries consumption of construction material is increased. Again with the industrial development waste material generation is occurring in a massive quantity.

In this present work the main objective is to determine the acceptability of stone dust as replacing substance of both binding material and fine aggregate in mortar in respect of the normal strength. In this research every possible combination were tested to investigate the exact percentages of stone dust which ensures inclusion of best percentages of stone dust than any other previous research. This study ensures the stone powder as an appropriate alternative of sand (fine aggregate) in mortar manufacturing as a building materials.

2. Materials for mortar specimen

The main constituents for mortar specimen are cement, sand, two types’ stone dust and water.

Table 1 Physical and chemical properties of portland cement

Portland cement properties	
Physical properties	
Initial Setting Time (minute)	64
Final Setting Time (minute)	121
Specific Surface Area (cm^2/gm)	3907
28 Days Compressive Strength (MPa)	31.5
Chemical properties	
Calcium Oxide (CaO)	62.25%
Silicon Dioxide (SiO_2)	21%
Aluminum Oxide (Al_2 O_3)	5.9%
Sulphur Trioxide (SO_3)	2.4%
Ferric Oxide (Fe_2O_3)	3.4%
Magnesium Oxide (MgO)	1.5%
Sodium Oxide (Na_2O)	0.2%
Potassium Oxide (K_2O)	0.45%
Loss of Ignition	1.1%

Table 2 Sieve analysis data

Sieve size	Cumulative mass retained (g)	Cumulative percent (%) retained
4.75 mm (No. 4)	47.25	6.3
2.36 mm (No. 8)	148.65	19.8
1.18 mm (No. 16)	293.4	39.1
600 µm (No. 30)	460.05	61.3
300 µm (No. 50)	550.8	73.4
150 µm (No. 100)	724.2	96.5
Pan	750.2	100

2.1 Portland cement

For this study high strength Portland cement was used. The physical and chemical properties of cement were obtained from the lab result and tabulated in Table 1.

2.2 Sand

Graded river sand was used to make the mortar specimens. Through sieve analysis by standard sieve, Fineness Modulus (FM) of sand was calculated and sieve analysis data is shown in Table 2. The FM of the sand was 2.96. Sand samples were washed and dried so that there should not remain any dust particle. They were free from organic chemicals and unwanted clay.

2.3 Stone dust

Stone dust was collected from nearby stone crushing plant to have exact quality in field. The specific surface area of stone dust replaced for cement in mortar specimen was 2529cm^2/gm and specific surface area of cement was 3907 cm^2/gm. It signifies that the size of dust particle is larger than the cement particle. Stone dusts were processed in two forms, one for the replacement of sand and another for the replacement of cement. For sand replacement the gradation and fineness modulus of stone dust was tried to keep similar to the sand. The fineness modulus (FM) of stone dust was about 2.65 and stone dust retained at no. 100 sieve was selected for sand replacing stone dust. Stone dust passing by No. 200 sieve was used as cement replacing material.

2.4 Wate

Normal drinking water was used and it was collected from available source.

3. Mortar specimens preparation

Cube and Briquette specimens were casted in this research purpose to get some clear idea about both compressive strength and tensile strength. Mortar materials for compressive strength test were mixed according to ASTM C109 standard. On the contrary, for tensile strength test it was mixed according to ASTM C109 and CRD-C 260-01. The water cement ratio for mortar without stone dust was 0.40. Water cement ratio for the mortar specimens with stone dust was varied from 0.40 to 0.45. Water demand increases with the increase of stone dust content in mortar.

Dimension of the cube mold for compressive strength test was 5.08 cm x 5.08 cm x 5.08 cm. Casted cube specimens with molds are shown in Fig. 1.

Standard dimension briquette molds were used for preparing briquette specimens for tensile strength test. Total 36 types of specimen were casted with different percentages of stone dust by replacing both sand and cement. Though stone dust is not a binder material, very fine stone dusts were used as a replacement of cement to investigate that is there any micro filling effect or capabilities of stone dust exist or not. Moreover, another purpose is to investigate the combine effect when both sand and cement were replaced partially. Every possible combination was ensured to find out most accurate and specific percentage ratio of stone dust for replacing cement and sand. That means for determining compressive strength at 7 days 72 specimens, compressive strength at 28 days 72 specimens and tensile strength at 28 days 72 specimens were casted. The mixture proportions of all specimens are tabulated in Table 3.

Fig. 1 Cube specimen casting

Table 3 Specimen mixture proportions

Specimen name	Sand replacing stone dust (%)	Cement replacing stone dust (%)
S1	0	0
S2	0	3
S3	0	5
S4	0	7
S5	15	0
S6	15	3
S7	15	5
S8	15	7
S9	20	0
S10	20	3
S11	20	5
S12	20	7
S13	25	0
S14	25	3
S15	25	5
S16	25	7
S17	30	0
S18	30	3
S19	30	5
S20	30	7
S21	35	0
S22	35	3
S23	35	5
S24	35	7
S25	40	0
S26	40	3
S27	40	5
S28	40	7
S29	45	0
S30	45	3
S31	45	5
S32	45	7
S33	50	0
S34	50	3
S35	50	5
S36	50	7

In case of specimen preparation, sand and binder materials were mixed perfectly in dry condition and then according to water binder ratio, weighted amount of water was added to the homogenous mixture. Cement-Sand ratio was taken as 2.5. For both cube and briquette molds were prepared with mold oil so that the surfaces of the molds remain free from disturbance. After filling mortar in molds, each layer was compacted with not less than 35 strokes per layer using a tamping rod. The tamping rod was a steel bar with 16mm diameter and 60cm long, bullet pointed at lower end. After this the top surface was levelled and smoothen it with a trowel.

4. Mortar specimens curing and testing

4.1 Curing

Curing is very important to ensure proper strength and workability of mortar. On this research, considering about curing was a special concern because properly cured mortar has an adequate amount of moisture which helps to mortar specimen continuing its hydration process as well as strength development. Resisting from freezing and thawing, abrasion and scaling resistance also ensured by proper curing. The mortar specimens were removed from molds after 24 hours of casting. Ponding and immersion curing technique was applied for this experiment. Proper care was taken to maintain curing water temperature 20℃ ± 2℃ and over 95% relative humidity. Humidity is controlled by water nebulizers. Special concentrations were given to keep specimens undisturbed until crashing. Just before placing Testing Machine, the mortar specimens were kept under sun for some period, so that they can overcome the effect of water at its surface.

4.2 Test setup

The cube specimens were tested after 7 and 28 days. Meanwhile, briquette specimens were tested after 28 days. Compressive strength test was performed via Universal Testing machine at a constant loading rate. Because of some technical problem Digital Machine cannot be used during the research time. But calibration was done with 100% accuracy for conventional testing machine. Moreover, the load was controlled and observed with special care. The machine was equipped for applying the load at the defined rate, consistently without abrupt shock. The rate of error is not surpassing ±1.0 percent of the indicated load. The arrangement of specimen in the testing machine is shown in Fig. 2. The average from two specimens of each type was recorded for the compressive strength. Tensile strength test of briquette specimen was also performed with the same mixture of different types and an average of two specimens of each type was recorded for the tensile strength.

Fig. 2 Cube specimen in testing machine

5. Results and discussions

5.1 Compressive strength

The development of compressive strength at 7 and 28 days are shown in Fig. 3 and Fig. 4 respectively. The study shows that, the highest value of compressive strength for 7 days is 45.10 MPa and for 28 days it is 58.25 MPa and in both cases it was obtained from Mortar Specimen S22 (marked with green color in Fig. 3 and Fig. 4). At 7 and 28 days compressive strength of S22 specimen increases around 21.33% and 22.76% respectively than the control specimen (S1). S21 exhibits 2nd highest value of compressive strength for 7 days but S18 for 28 days. Though for 28 days, value of S18 and S21 are too close. At 7 and 28 days, compressive strength of S21 specimen increases around 15.44% and 20.08% respectively than control specimen, S1.

5.2 Tensile strength

In Fig. 5, test result of 28 days tensile strength shown clearly. As mentioned earlier the 28 days tensile strength value for tensile strength was determined. Highest tensile strength value was achieved for specimen S21 (marked with green color in Fig. 5). The value is 2.78 MPa and it is around 13.47% increased than control mortar specimen S1. Second maximum strength obtained from S22.

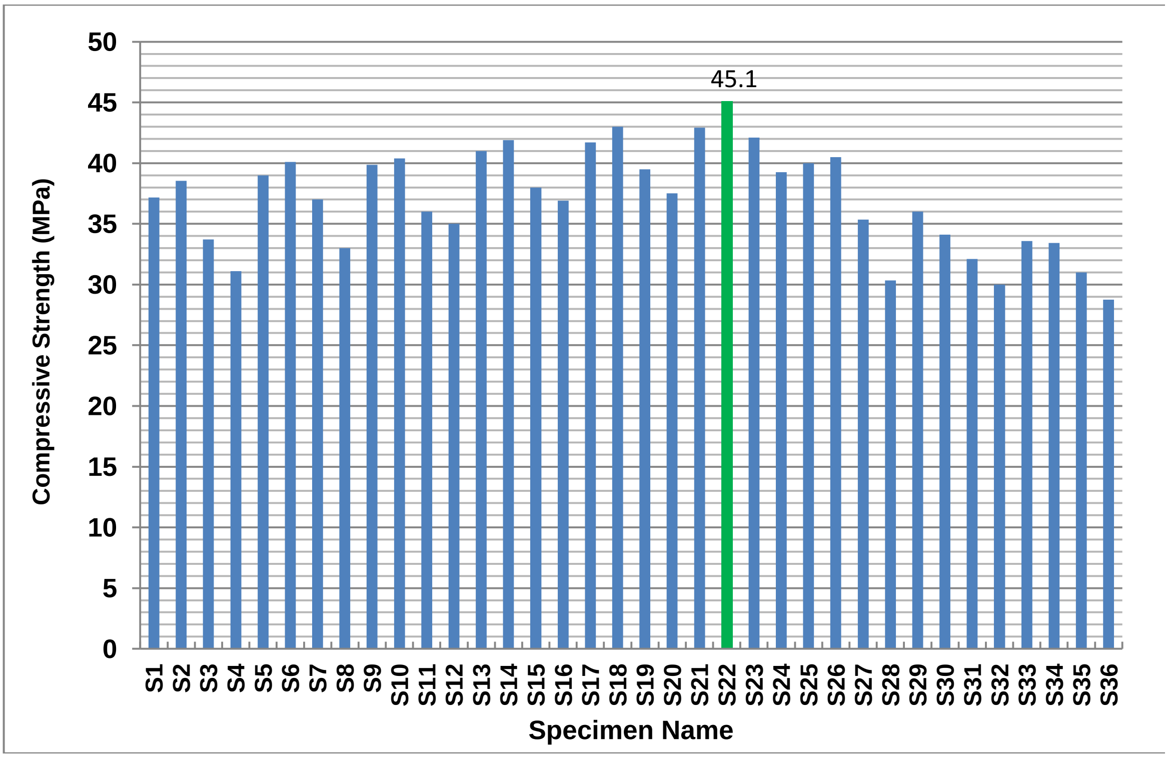

Fig. 3 Compressive strength (MPa) at 7 Days

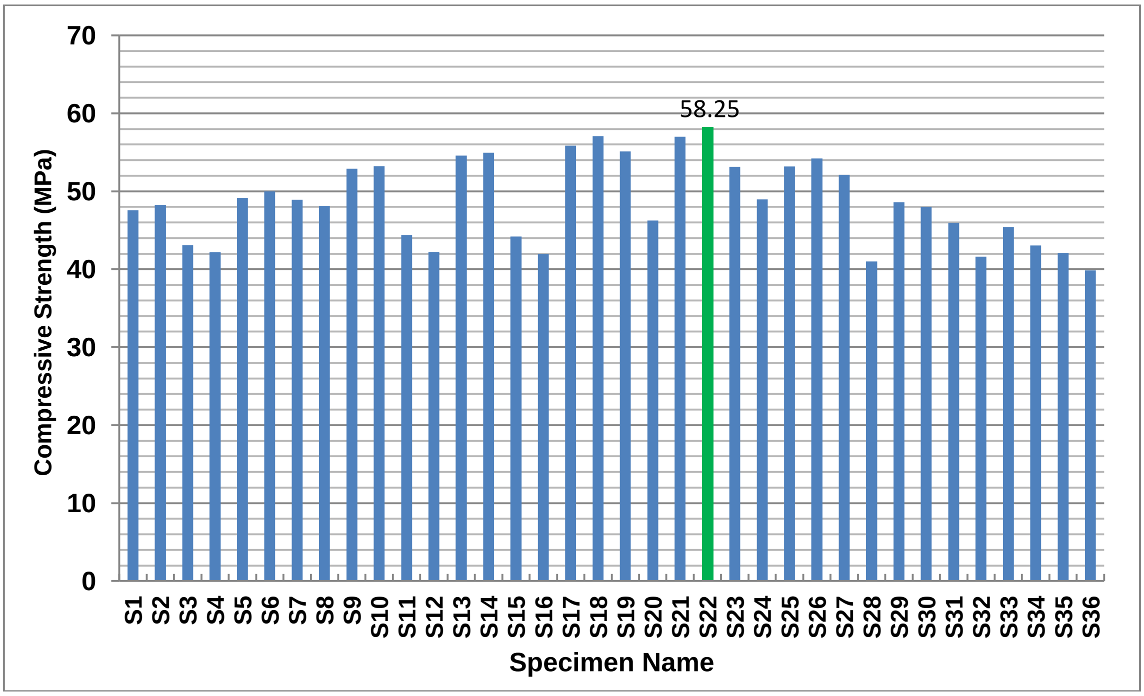

Fig. 4 Compressive strength (MPa) at 28 Days

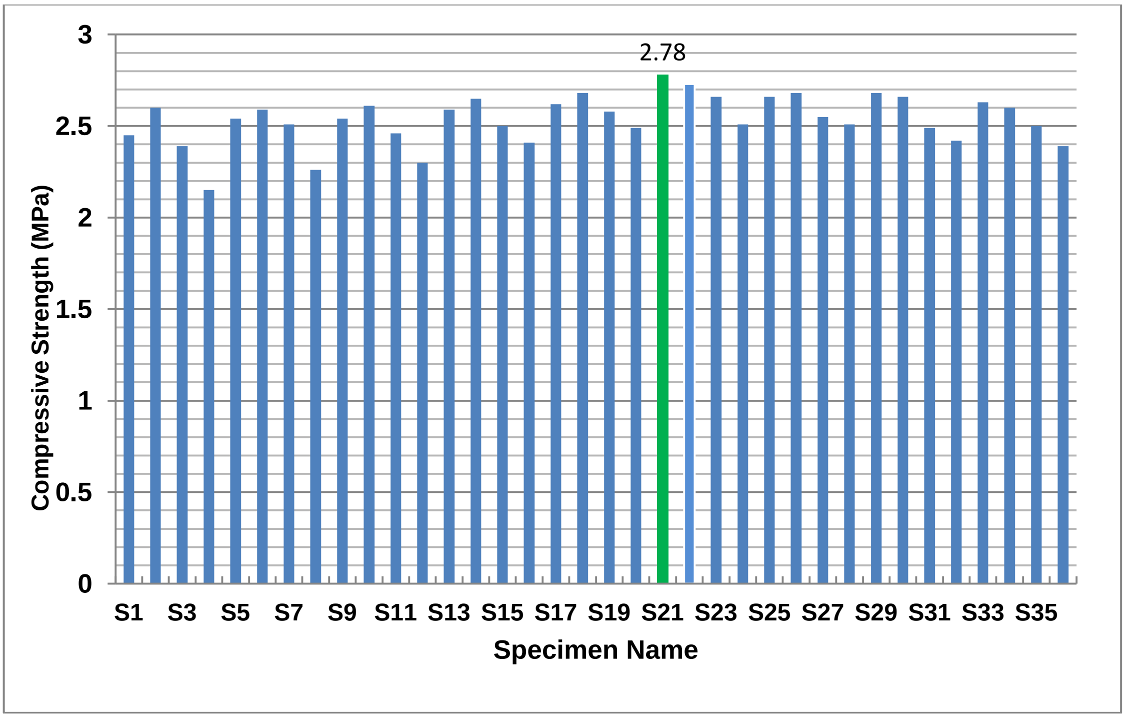

Fig. 5 Tensile strength (MPa) at 28 Days

5.3 Data analysis

By analyzing all of the data obtained from this research, at the end some important discussions were evaluated. Stone dust is not a waste material rather it can use as a sustainable material for sand and cement. Stone dust has a strong contribution to increase the strength of mortar but it has a fixed ratio and percentages. Beyond this percentages, compressive and tensile strength of mortar decreases significantly. In this research, every possible combination was tested to investigate the exact percentages of stone dust which ensures inclusion of best percentages of stone dust than any other previous research. It also ensures that, dependency on valuable sand and cement by using stone dust can be decreased. It will help to minimize the stone dust waste as well as ensure good strength for mortar.

In this research, for compressive strength (28 days) S22 sample shows maximum and S21 sample 2nd maximum (close to sample S18). For tensile strength (28 days) S21 sample shows maximum and S22 sample shows 2nd maximum value. By cross check, percentages of sample S22 (35% of Sand Replacing Stone Dust + 3% of Cement Replacing Stone Dust) can be used for whole construction as it is the ‘optimum dosage’ proportion. The probable reason of getting good strength at S22 is that, the presence of stone dust at sand increases the water demand as well as increase the filler effect. These effects increase and ensure the dense packing of the materials. Dust particle completed matrix interstices and reduce the space for free water. It may cause strength increment. Moreover, the shape of normal sand is irregular and surface texture is not well defined, that’s why inter particle bond is not better as like fine stone dust. By the way, for both compressive strength and tensile strength data, it can be said that – if cement is replaced by more than 5% stone dust by weight of cement, it causes detrimental effect to strength. That’s why using stone dust beyond optimum amount (3% stone dust by weight of cement) is not preferable for cement replacement. Cement should not be replaced in excessive amount and only 3% with stone dust seems to be satisfactory.

5.4 Specimen crack analysis

The crack pattern of control mortar specimen and modified mortar specimens were observed closely. For observing this more accurately, after initial crack formation – loading was stopped for few minutes. Again final failure pattern also observed after final failure. For modified mortar specimen initial cracks were formed in higher loads than normal mortar sample. But there was no noticeable difference in crack pattern between normal and modified mortar specimen. But in case of pattern of final failure, some difference had been noticed. For normal mortar specimen cube the failure seems to be brittle but in modified mortar specimen the final failure was not fully brittle. It showed some ductility before finally crushed. Moreover, for modified mortar sample the final failure occurred in the upper part of the specimen not in the center while for normal mortar specimen, failure propagation enter into center little bit which is normal failure behavior of mortar. The picture of final failure of modified mortar is shown in Fig. 6

It is important to mention that, after curing very few micro-cracks found in the surface of almost every specimen and it was may be due to internal shrinkage. In naked eye those micro-cracks were not seen and to observe those cracks magnifying glass was used. But those cracks are not significantly responsible for strength. The extended and further studies of this research will cover hydration and internal stress development of mortar specimen (both normal and modified) corresponding to time. But from this research, it is pretty sure that – using of ambient amount of stone dust resist crack formation as well as crack propagation.

Fig. 6 Final failure pattern of modified mortar cube specimen

6. Conclusion

According to the analysis of the whole study following conclusion can be drawn,

[1] Stone dust can be used as a replacement of sand in case of mortar preparation which gives good results in both compressive and tensile strength as well as in crack formation.

[2] By testing from every possible combination, the best percentage combination is evaluated and it is 35% of Sand Replacing Stone Dust with 3% of Cement Replacing Stone Dust. It will ensure best strengths both in compression and tensile.

[3] Using excessive stone dust as a replacement of cement is not preferable because from tested results it is proved that, if cement is replaced by more than 5% stone dust by weight of cement, it causes detrimental effect to strength. Stone dust is quite appropriate to be selected as the substitution of fine aggregate but not as the excessive replacement of cement.

[4] To resist the crack propagation and penetration into the center, stone dust may be a solution for mortar preparation industry.

[5] Stone dust may ensure a potential use and alternative to fine aggregate which minimize the waste products like stone dust generated in stone crushing industry. Thus the stone dust will introduced as a functional construction materials.

[6] Using of stone dust needs more water as stone dust is water absorbing material but it can be adjusted easily without sacrificing any strength.

[7] Effect of internal shrinkage and drying shrinkage was not considered in this research and it will conduct in further studies for mortar with stone dust.

From this intensive research it is possible to know that depending on the percentage of using and type of replacing stone dust may have both positive and negative effect on mortar strength. So use of favorable stone dust is very important which truly helps to make best use of some waste material and ensure sustainable development.

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